

Mesh Profile

Bluetooth® Specification

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Abstract:

This Bluetooth specification defines fundamental requirements to enable an interoperable mesh networking solution for Bluetooth low energy wireless technology.



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1 Introduction

The Bluetooth Mesh Profile specification defines fundamental requirements to enable an interoperable mesh networking solution for Bluetooth low energy wireless technology.

1.1 Conformance

If conformance to this specification is claimed, all capabilities indicated as mandatory for this specification shall be supported in the specified manner (process-mandatory). This also applies for all optional and conditional capabilities for which support is indicated.

1.2 Bluetooth specification release compatibility

This specification shall be used with:

- Core Specification Addendum 6 [3] combined with an allowed Bluetooth Core Specification (see [3] Volume 1, Part D, Section 1.2, Table 1.3), OR
- Any version of the Bluetooth Core Specification later than v5.0.

The Generic Attribute Profile (GATT) is required if the GATT provisioning bearer defined in Section 5.2.2 is supported or if the GATT bearer defined in Section 3.3.2 is supported.

1.3 Language

1.3.1 Language conventions

The Bluetooth SIG has established the following conventions for use of the words **shall**, **must**, **will**, **should**, **may**, **can**, **is**, and **note** in the development of specifications:

shall	<u>is required to</u> – used to define requirements
must	is used to express: a natural consequence of a previously stated mandatory requirement. OR an indisputable statement of fact (one that is always true regardless of the circumstances).
will	<u>it is true that</u> – only used in statements of fact
should	<u>is recommended that</u> – used to indicate that among several possibilities one is recommended as particularly suitable, but not required
may	<u>is permitted to</u> – used to allow options
can	<u>is able to</u> – used to relate statements in a causal manner
is	<u>is defined as</u> – used to further explain elements that are previously required or allowed



note	Used to indicate text that is included for informational purposes only and is not required in order to implement the specification. Each note is clearly designated as a “Note” and set off in a separate paragraph.
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For clarity of the definition of those terms, see Core Specification Volume 1, Part E, Section 1.

1.3.2 Reserved for Future Use

Where a field in a packet, Protocol Data Unit (PDU), or other data structure is described as "Reserved for Future Use" (irrespective of whether in uppercase or lowercase), the device creating the structure shall set its value to zero unless otherwise specified. Any device receiving or interpreting the structure shall ignore that field; in particular, it shall not reject the structure because of the value of the field.

Where a field, parameter, or other variable object can take a range of values and some values are described as "Reserved for Future Use," a device sending the object shall not set the object to those values. A device receiving an object with such a value should reject it, and any data structure containing it, as being erroneous; however, this does not apply in a context where the object is described as being ignored or it is specified to ignore unrecognized values.

When a field value is a bit field, unassigned bits can be marked as Reserved for Future Use and shall be set to 0. Implementations that receive a message that contains a Reserved for Future Use bit that is set to 1 shall process the message as if that bit was set to 0, except where specified otherwise.

The acronym RFU is equivalent to "Reserved for Future Use."

1.3.3 Prohibited

When a field value is an enumeration, unassigned values can be marked as “Prohibited.” These values shall never be used by an implementation, and any message received that includes a Prohibited value shall be ignored and shall not be processed and shall not be responded to.

Where a field, parameter, or other variable object can take a range of values, and some values are described as “Prohibited,” devices shall not set the object to any of those Prohibited values. A device receiving an object with such a value should reject it, and any data structure containing it, as being erroneous.

“Prohibited” is never abbreviated.

1.3.4 Acronyms and abbreviations

Abbreviation or Acronym	Meaning
ACK	Acknowledgment
AD	Advertising Data
AES	Advanced Encryption Standard
AID	Application Key Identifier
AKF	Application Key Flag
ASCII	American Standard Code for Information Interchange



Abbreviation or Acronym	Meaning
ATT	Attribute Protocol
ATT_MTU	Attribute Protocol Maximum Transmission Unit
BR/EDR	Basic Rate / Enhanced Data Rate
CCM	Counter with CBC-MAC
CID	Company Identifier
CMAC	Cipher-based Message Authentication Code
CTL	Network control message indication
DST	Destination
ECB	Electronic CodeBook
ECDH	Elliptic Curve Diffie-Hellman
FCS	Frame Check Sequence
FIPS	Federal Information Processing Standards
FSN	Friend Sequence Number
GAP	Generic Access Profile
GATT	Generic Attribute Profile
ID	Identifier
IEEE	Institute of Electrical and Electronics Engineers
IKM	Input Key Material
IVI	Initialization Vector Index
JSON	JavaScript Object Notation
LED	Light Emitting Diode
LSO	Least Significant Octet
MAC	Message Authentication Code
MD	More Data
MIC	Message Integrity Check
MSO	Most Significant Octet
MTU	Maximum Transmission Unit
NID	Network Identifier
OBO	On Behalf Of (another element)
OKM	Output Key Material
OOB	Out of Band
PDU	Protocol Data Unit
PID	Product Identifier
RFU	Reserved for Future Use
RPL	Replay Protection List



Abbreviation or Acronym	Meaning
RSSI	Received Signal Strength Indicator
SAR	Segmentation And Reassembly
SEG	Segmentation indication bit
SEQ	Sequence Number
SIG	Special Interest Group
SRC	Source
SZMIC	Size of Message Integrity Check
TTL	Time To Live
URI	Uniform Resource Indicator
UUID	Universally Unique Identifier
VID	Version Identifier
WG	Working Group

Table 1.1: Abbreviations and acronyms

1.3.5 Terminology

Term	Definition
Address	The identity of one or more elements in one or more nodes.
Configuration Client	A node that implements the Configuration Client model.
Destination	The address to which a message is sent.
Device	An entity that is capable of being provisioned onto a mesh network.
Element	An addressable entity within a device. A device is required to have at least one element.
Message	A sequence of octets that is sent from a source to a destination.
Neighbors	Nodes in direct radio range (single hop).
Network	A group of nodes sharing a common address space.
Node	A provisioned device.
Provision	The process of authenticating and providing basic information (including unicast addresses and a network key) to a device. A device must be provisioned to become a node. Once provisioned, a node can transmit or receive messages in a mesh network.
Provisioner	A node that is capable of adding a device to a mesh network.
Relay	A node that receives and then retransmits messages.
Source	The address from which a message is sent.

Term	Definition
State	A value representing a condition of an element that is exposed by an element of a node.
Subnet	A group of nodes that can communicate with each other.

Table 1.2: Terminology

2 Mesh system architecture

This section provides an overview of the mesh network operation and layered system architecture.

2.1 Layered architecture

The Mesh Profile specification is defined as a layered architecture as shown in [Figure 2.1](#).

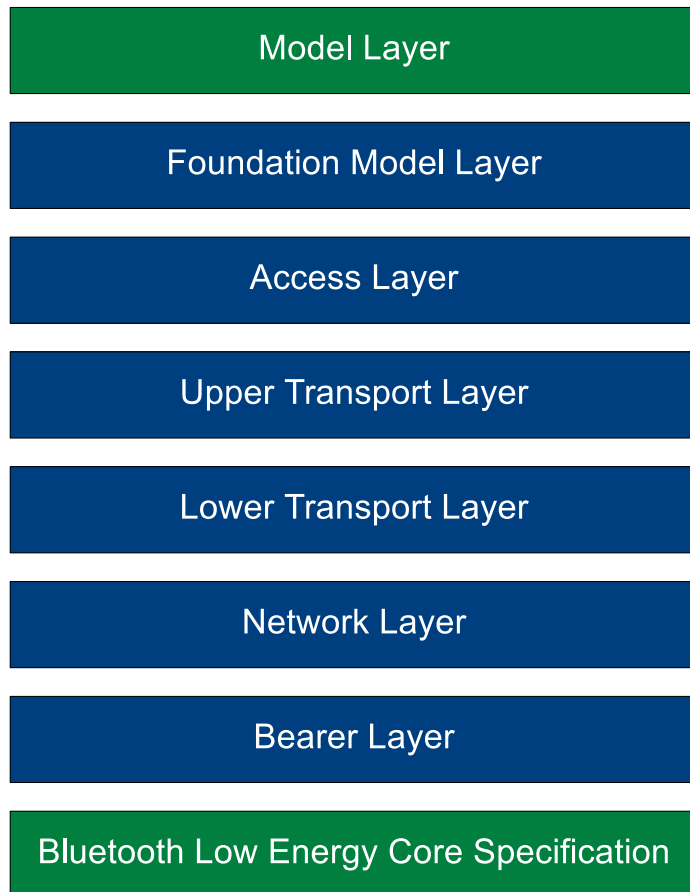


Figure 2.1: Mesh system architecture

2.1.1 Model layer

The Model layer defines models that are used to standardize the operation of typical user scenarios and are defined in the Bluetooth Mesh Model specification [11] or other higher layer specifications. Examples of higher layer model specifications include models for lighting and sensors.

2.1.2 Foundation Model layer

The Foundation Model layer defines the states, messages, and models required to configure and manage a mesh network.

2.1.3 Access layer

The access layer defines how higher layer applications can use the upper transport layer. It defines the format of the application data; it defines and controls the application data encryption and decryption performed in the upper transport layer; and it checks whether the incoming application data has been received in the context of the right network and application keys before forwarding it to the higher layer.

2.1.4 Upper transport layer

The upper transport layer encrypts, decrypts, and authenticates application data and is designed to provide confidentiality of access messages. It also defines how transport control messages are used to manage the upper transport layer between nodes, including when used by the Friend feature.

2.1.5 Lower transport layer

The lower transport layer defines how upper transport layer messages are segmented and reassembled into multiple Lower Transport PDUs to deliver large upper transport layer messages to other nodes. It also defines a single control message to manage segmentation and reassembly.

2.1.6 Network layer

The network layer defines how transport messages are addressed towards one or more elements. It defines the network message format that allows Transport PDUs to be transported by the bearer layer. The network layer decides whether to relay/forward messages, accept them for further processing, or reject them. It also defines how a network message is encrypted and authenticated.

2.1.7 Bearer layer

The bearer layer defines how network messages are transported between nodes. There are two bearers defined, the advertising bearer and the GATT bearer. Additional bearers may be defined in the future.

2.2 Overview of mesh operation

The mesh network operation defined by this specification is designed to:

- enable messages to be sent from one element to one or more elements;
- allow messages to be relayed via other nodes to extend the range of communication;
- secure messages against known security attacks, including eavesdropping attacks, man-in-the-middle attacks, replay attacks, trash-can attacks, brute-force key attacks, and possible additional security attacks not documented here;
- work on existing devices in the market today;
- deliver messages in a timely manner;
- continue to work when one or more devices are moved or stop operating; and
- have built-in forward compatibility to support future versions of the Mesh Profile specification.



This specification defines a managed-flood-based mesh network, which uses broadcast channels to transmit messages so that other nodes can receive messages and relay these messages; thus extending the range of the original message. Any device in a managed-flood mesh network can send a message at any time as long as there is a sufficient density of devices that are listening and relaying messages. Enhancements to add routing functionality and define a routing-based mesh network may be considered for a future revision of this specification.

There are a number of methods used by this specification to restrict the unlimited relaying of messages in a managed-flood mesh network. The two main methods used are the network message cache method and the time to live method.

The network message cache is designed to prevent devices from relaying previously received messages by adding all messages to a cached list. When a message is received, it is checked against the list and ignored if already present. If not already received, then it is added to the cache so that it can be ignored in the future. To prevent this list from becoming too long, the number of messages that are cached is limited by implementation.

Each message includes a Time to Live (TTL) value that limits the number of times a message can be relayed. Each time a message is received and then relayed (up to a maximum of 126 times) by a device, the TTL value is decremented by 1.

2.2.1 Network and subnets

A mesh network consists of nodes sharing four common resources:

- network addresses used to identify source and destination of messages (see Section 3.4.2);
- network keys used to secure and authenticate messages at the network layer (see Section 3.8.6.3);
- application keys used to secure and authenticate messages at the access layer (see Section 3.8.6.2); and
- an IV Index used to extend the lifetime of the network (see Section 3.8.4).

A network can have one or more subnets that facilitate "area" isolation (e.g., isolated hotel room subnets within a hotel network). A subnet is a group of nodes that can communicate with each other at a network layer because they share a network key. A node may belong to one or more subnets by knowing one or more network keys. At the time of provisioning, a device is provisioned to one subnet and may be added to more subnets using the Configuration Model.

There is one special subnet called the primary subnet, which is based on the primary NetKey (see Section 3.8.6.4). Nodes on the primary subnet participate in the IV Update procedure (see Section 3.10.5), and propagate IV updates to other subnets, while nodes on other subnets only propagate the IV Index updates to those subnets.

The network resources are managed by a node that implements the Configuration Client model, known as the Configuration Client, (typically a smart phone or other mobile computing device) and are allocated to nodes at the time of configuration (see Section 5) using the Configuration Server model (see Section 4.4.1). In particular, a Provisioner manages allocation of addresses to make sure no duplicate unicast addresses are allocated, whereas a Configuration Client generates and distributes network and



application keys and makes sure that devices that need to communicate with each other share proper keys for both network and access layers. The Configuration Client also knows device keys (see Section 3.8.6.1), which are used to secure communication with each individual node, including distributing updated network and application keys.

2.2.2 Devices and nodes

A device that is not a member of a mesh network is known as an unprovisioned device. A device that is a member of a mesh network is known as a node. A Provisioner is used to manage the transitions between an unprovisioned device and a node.

An unprovisioned device cannot send or receive mesh messages; however, it advertises its presence to Provisioners. A Provisioner will invite an unprovisioned device into a mesh network after it has been authenticated, converting the unprovisioned device into a node.

A node can send or receive mesh messages and is managed by a Configuration Client, that may also be the same device as the Provisioner, over the mesh network to configure how the node communicates with other nodes. A Configuration Client can remove a node from a mesh network, which reverts it back to an unprovisioned device.

A device may support multiple instances of a node by offering itself to be provisioned to another mesh network after already being provisioned to a mesh network. Each instance of a mesh network is determined by addresses and a device key obtained by the device during provisioning.

2.2.3 Adding devices to a mesh network

Devices are added to a mesh network by a Provisioner, at which point they become nodes. The provisioning of devices into a mesh network differs from the point-to-point bonding and pairing that is typically used in Bluetooth wireless technology. Provisioning of devices is enabled using either a simple advertising bearer or a point-to-point GATT-based bearer. A single provisioning protocol is used over both bearers. Provisioning over an advertising-based bearer is implemented by all devices. Provisioning over a GATT-based bearer allows devices such as legacy phones (i.e., devices that do not support provisioning over an advertising bearer natively) to be Provisioners.

To assist with provisioning of multiple devices, a device has an attention timer that can be set by a Provisioner. When set to a non-zero value, the device identifies itself using any means it can. For example, the device may flash a light, make a sound, or vibrate. When the attention timer expires, the device stops identifying itself. This allows a Provisioner to send a single message to a device to cause it to identify itself and the device automatically stops identifying itself after a given time.

The protocol to run over these two bearers is a derivative of the Security Manager protocol of v4.2 of the Bluetooth Core Specification to introduce the ability to authenticate devices that have a very limited user interface, such as a light or a switch. The Security Manager protocol requires a reliable bearer, something that cannot be guaranteed by the advertising provisioning bearer; therefore the protocol used in this specification is designed to enable reliable delivery of messages independent of the bearer. The similarity to the Security Manager protocol enables significant reuse of existing code on devices that have implemented such functionality.

2.2.4 Communications support

Many current devices are unable to advertise or comprehend mesh messages without being updated. To enable these devices to communicate with a node in a mesh network without the need for an operating system update or similar hardware/software update, the specification enables the use of GATT connectivity for all existing devices.

2.2.5 Low power support

The features within this specification enable many devices in the mesh network to be battery-powered or to use techniques such as energy harvesting. Such devices may be constrained in how they can function as a part of a mesh network (e.g., devices that only send data when interacted with). This specification does not require devices to coordinate transmissions, make connections, or restart security on every connection; thus facilitating low power operation. Devices needing low power support can associate themselves with an always-on device that stores and relays messages on their behalf, using the concept known as Friendship (see Section 3.6.6). However, devices that relay messages will receive messages as well as forward messages a majority of the time and are likely to use significantly more power than could be provided by typical small batteries or capacitors.

2.3 Architectural concepts

The mesh networking architecture uses several different concepts: states, messages, bindings, elements, addressing, models, publish-subscribe, mesh keys, and associations.

2.3.1 States

A state is a value representing a condition of an element.

An element exposing a state is referred to as a server. For example, the simplest server is a Generic OnOff Server, representing that it is either on or off.

An element accessing a state is referred to as a client. For example, the simplest client is a Generic OnOff Client (a binary switch) that is able to control a Generic OnOff Server via messages defined by the Generic OnOff Model.

States that are composed of two or more values are known as composite states. For example, a color-changing lamp can control color hue separately from color saturation and brightness.

2.3.2 Bound states

When a state is bound to another state, a change in one results in a change in the other. Bound states may be from different models in one or more elements. For example, a common type of binding is between a Level state and an OnOff state: changing the Level to 0 changes the bound OnOff state to Off and changing the Level to a non-zero value changes the bound OnOff state to On.

2.3.3 Messages

All communication within a mesh network is accomplished by sending messages. Messages operate on states. For each state, there is a defined set of messages that a server supports and a client may use to request a value of a state or to change a state. A server may also transmit unsolicited messages carrying information about states and/or changing states.



A message is defined as having an opcode, associated parameters, and behavior. An opcode may be a single octet (for special messages that require maximum possible payload for parameters), 2 octets (for standard messages), or 3 octets (for vendor-specific messages).

A total message size, including an opcode, is determined by the underlying transport layer, which may use a Segmentation and Reassembly (SAR) mechanism. To maximize performance and avoid the overhead of SAR, a design goal is to fit messages in a single segment. The transport layer provides up to 11 octets for a non-segmented message, leaving up to 10 octets that are available for parameters when using a 1-octet opcode, up to 9 octets available for parameters when using a 2-octet opcode, and up to 8 octets available for parameters when using a vendor-specific 3-octet opcode.

The transport layer provides a mechanism of SAR capable of transporting up to 32 segments. The maximum message size when using the SAR is 384 octets. This means (excluding an Application MIC) up to 379 octets are available for parameters when using a 1-octet opcode, up to 378 octets are available for parameters when using a 2-octet opcode, and up to 377 octets are available for parameters when using a vendor-specific 3-octet opcode.

SAR effectively does not impose any extra overhead on the access layer payload per segment: a 10-octet message is transported as an unsegmented message, and a 20-octet message is transported as a segmented message that uses two segments.

Message definitions contain tables of parameters. In a message payload, parameters follow an opcode, and parameter offsets are in octets unless otherwise specified.

Messages are defined as acknowledged or unacknowledged. An acknowledged message requires a response whereas an unacknowledged message does not require a response.

2.3.4 Elements

An element is an addressable entity within a node. Each node has at least one element, the primary element, and may have one or more additional secondary elements. The number and structure of elements is static and does not change throughout the lifetime of a node (that is, as long as the node is part of a network).

The primary element is addressed using the first unicast address assigned to the node during provisioning. Each additional secondary element is addressed using the subsequent addresses. These unicast element addresses allow nodes to identify which element within a node is transmitting or receiving a message.

If the number and structure of elements changes, for example due to a firmware update, the node must be reprovisioned. The Node Removal procedure (see Section 3.10.7) is used when a firmware update is performed that changes the number or structure of elements.

Messages are dispatched within models based on opcodes and element addresses.

An element is not allowed to contain multiple instances of models that use the same message in the same way (for example, receive an “On” message). When multiple models within the same element use the same message, the models are said to “overlap.” To implement multiple instances of overlapping models within a single node (for example, to control multiple light fixtures that can be turned on and off), the node is required to contain multiple elements.

For example, a light fixture may have two lamps, each implementing an instance of the Light Lightness Server model and an instance of the Generic Power OnOff Server model. This requires that the node contain two elements, one for each lamp. When it receives an "On" message, the node uses the unicast address of the element to identify which instance of the Generic Power OnOff Server model the message is addressed to.

In another example, a dual-socket power strip contains two independent energy measurement sensors that can measure power consumed by an appliance connected to a socket. This would require that the node have two Sensor Data states, each in a separate element. The first element, the primary element, would be identified using the unicast address for the node and would include a state for the first energy sensor as well as states representing the configuration of the node. The second element, a secondary element, would be identified using a unicast element address and would include the state for the second energy sensor.

Each element has a GATT Bluetooth Namespace Descriptor [5] value that helps identify which part of the node this element represents. These namespace descriptor values use the same definitions as GATT. For example, the elements of the temperature sensor would use the values "inside" and "outside."

2.3.5 Addresses

An address may be a unicast address, a virtual address, or a group address. There is also a special value to represent an unassigned address that is not used in messages.

A unicast address is allocated to an element and always represents a single element of a node. There are 32767 unicast addresses per mesh network.

A virtual address is a multicast address and can represent multiple elements on one or more nodes. Each virtual address logically represents a Label UUID, which is a 128-bit value that does not have to be managed centrally. Each message sent to a Label UUID includes the full Label UUID in the message integrity check value that is used to authenticate the message. To reduce the overhead of checking every known Label UUID, a hash of the Label UUID is used. There are 16384 hash values, each of which codifies a set of virtual addresses. While there are only 16384 hash values used in a virtual address, each hash value can represent millions of possible Label UUIDs; therefore, the number of virtual addresses is considered very large.

A group address is a multicast address and can represent multiple elements on one or more nodes. There are 16384 group addresses per mesh network. There are a set of fixed group addresses that are used to address a subset of all primary elements of nodes based on the functionality of those nodes. All other group addresses are known as dynamically assigned group addresses. There are 256 fixed group addresses and 16128 dynamically assigned group addresses.

2.3.6 Models

A model defines the basic functionality of a node. A node may include multiple models. A model defines the required states (as described in Section 2.3.1), the messages that act upon those states (as described in Section 2.3.3), and any associated behavior.

A mesh application is specified using a client-server architecture communicating with a publish-subscribe paradigm. Due to the nature of mesh networks and the recognition that the configuration of behavior is

performed by a Configuration Client, an application is not defined in a single end-to-end specification such as a profile. Instead, an application is defined in a client model, a server model, and a control model.

This specification defines three types of model: server models, client models, and control models:

- **Server model:** A server model is composed of one or more states spanning one or more elements. The server model defines a set of mandatory messages that it can transmit or receive, the behavior required of the element when it transmits and receives such messages, and any additional behavior that occurs after messages are transmitted or received.
- **Client model:** A client model defines a set of messages (both mandatory and optional) that a client uses to request, change, or consume corresponding server states, as defined by a server model. The client model does not have state.
- **Control model:** A control model may contain client model functionality to communicate with other server models and server model functionality to communicate with other client models. A control model may also contain *control logic*, which is a set of rules and behaviors that coordinate the interactions between other models that the control model connects to.

A single device may include server, client, and control models.

For example, [Figure 2.2](#) shows the element-model structure for a device that implements a server model (Device C) with a state and supporting messages R, S, T, X, Y, Z; and two devices that implement a client model, with Device A supporting messages X, Y, and Z and Device B supporting messages R, S, T, and Z.

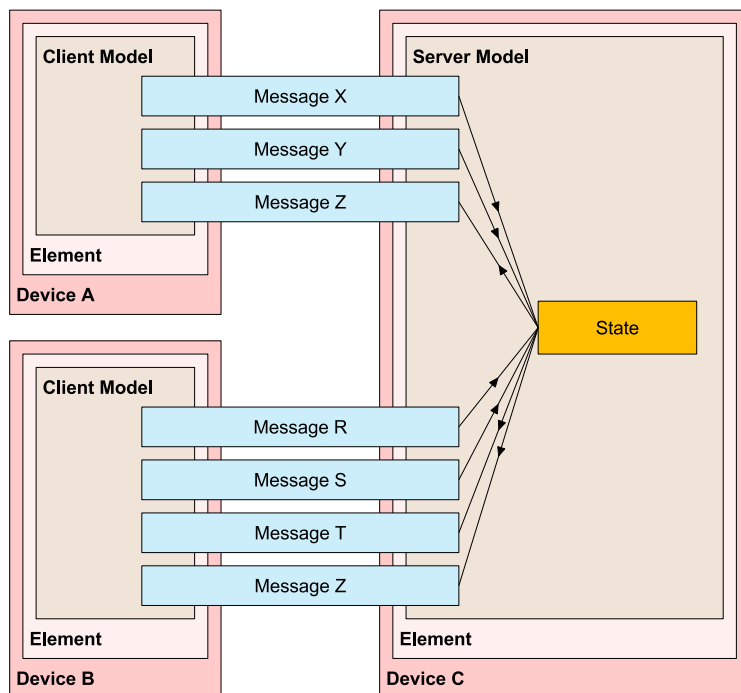


Figure 2.2: Client-server model communication

In another example, [Figure 2.3](#) shows the element-model structure of a device that implements a control model. Device C can communicate with server models as a client (supporting messages X, Y, and Z and messages R, S, and T respectively) and can communicate with client models as a server (supporting messages A, B, and C).

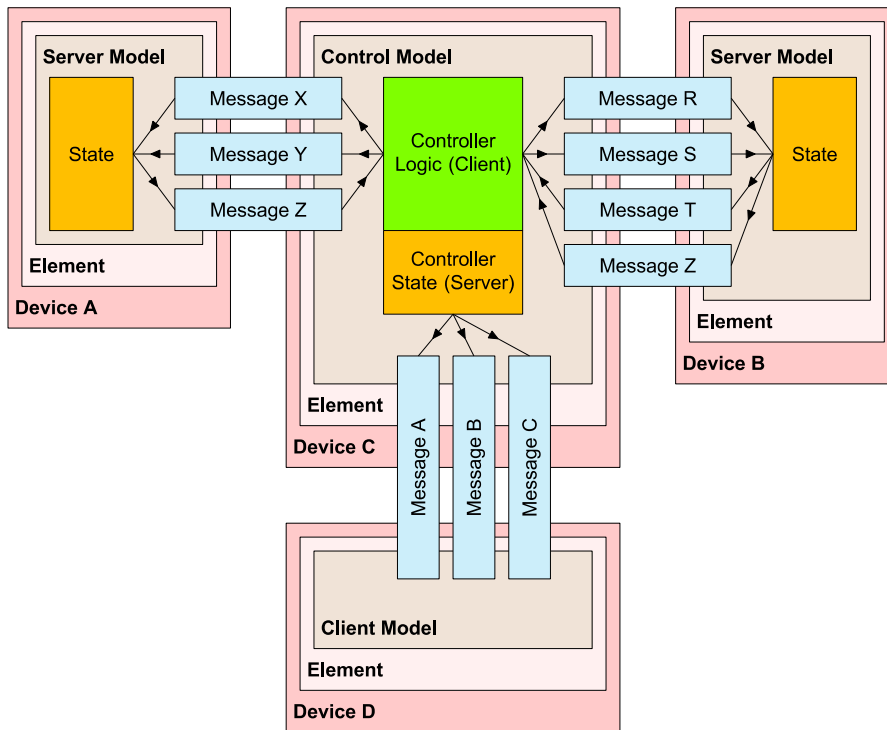


Figure 2.3: Control model communication

A lighting controller is an example of an implementation of a control model. The lighting controller needs to function as a client to sensors (to measure occupancy and/or ambient light) and to light sources (such as lamps or other luminaires). The lighting controller also would function as a server to a settings client (such as a smartphone application that configures its parameters). Such a lighting controller may be included within a sensor or light source or it may be a separate device.

Models can define functions of a device as a network node, such as key management, address assignment, and relaying of messages. Models also define physical behaviors of a device built around a network node, such as power control, lighting control, and sensor data collection. There may be nodes implementing only network-related functions, such as Relay nodes or Proxy nodes, while the majority of nodes are able to interact with the physical world by means of controlling electrical power, controlling light emissions, or sensing environmental data.

A message can be used by multiple different models. Message behavior is the same in each model, enabling a common understanding among client, server, and control models because the behavior is consistent regardless of the models that send and process the message.

Model specifications are designed to be very small and self-contained. A model can, at the specification definition time, require other models that must also be instantiated within the same node. This is called *extending*, which means a model can extend other models.

Models that do not extend other models are referred to as *root models*.

Model specifications are immutable: it is not possible to remove or add behavior to a model, whether the desired behavior is optional behavior or mandatory. Models are not versioned and have no feature bits. If additional behavior is required in a model, then a new extended model is defined that exposes the required behavior and can be implemented alongside the original model.

Therefore, knowledge of the models supported by an element determines the exact behavior exposed by that element.

Models may be defined and adopted by Bluetooth SIG and may be defined by vendors. Models defined by Bluetooth SIG are known as SIG adopted models, and models defined by vendors are known as vendor models. Models are identified by unique identifiers, which can be either 16 bits, for SIG adopted models, or 32 bits, for vendor models.

For example, [Figure 2.4](#) shows the element-model structure of a device that implements a root model with two bound states and a set of messages operating on each state. The root model is within the primary element and is extended by the extended model that adds another state on a secondary element. Messages are not capable of differentiating among multiple instances of the same state on the same element. Therefore, when more than one instance of a given state is present on a device, each instance is required to be in a separate element. In this example, the second instance of State X is required to be located on the second element because it is the same type of a state and thus has the same types of messages serving it.

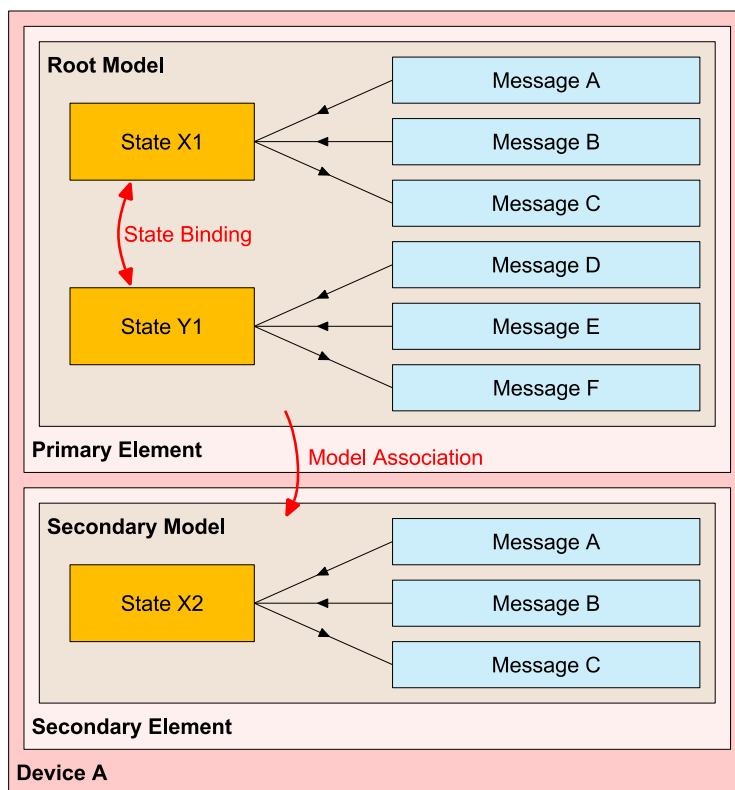


Figure 2.4: Element-model structure of a device



This example structure may be multiplied for a composite device. For example, a composite device may have multiple instances of the same root model (or extended models), each on a separate element (or set of elements). Also, if a model (root or extended) needs more than one instance of a particular state, the states must be distributed across several elements so that, at most, a single instance of any given state is on an element.

[Figure 2.5](#) illustrates how the element-model structure of the device in [Figure 2.4](#) might be implemented in a composite device. The element-model structure of the device is described by the Composition Data (see [Section 4.2.1](#)) that is read by a Configuration Client after provisioning (see [Section 5](#)), using the Configuration Server model and the Configuration Client model (see [Sections 4.4.1](#) and [4.4.2](#)).

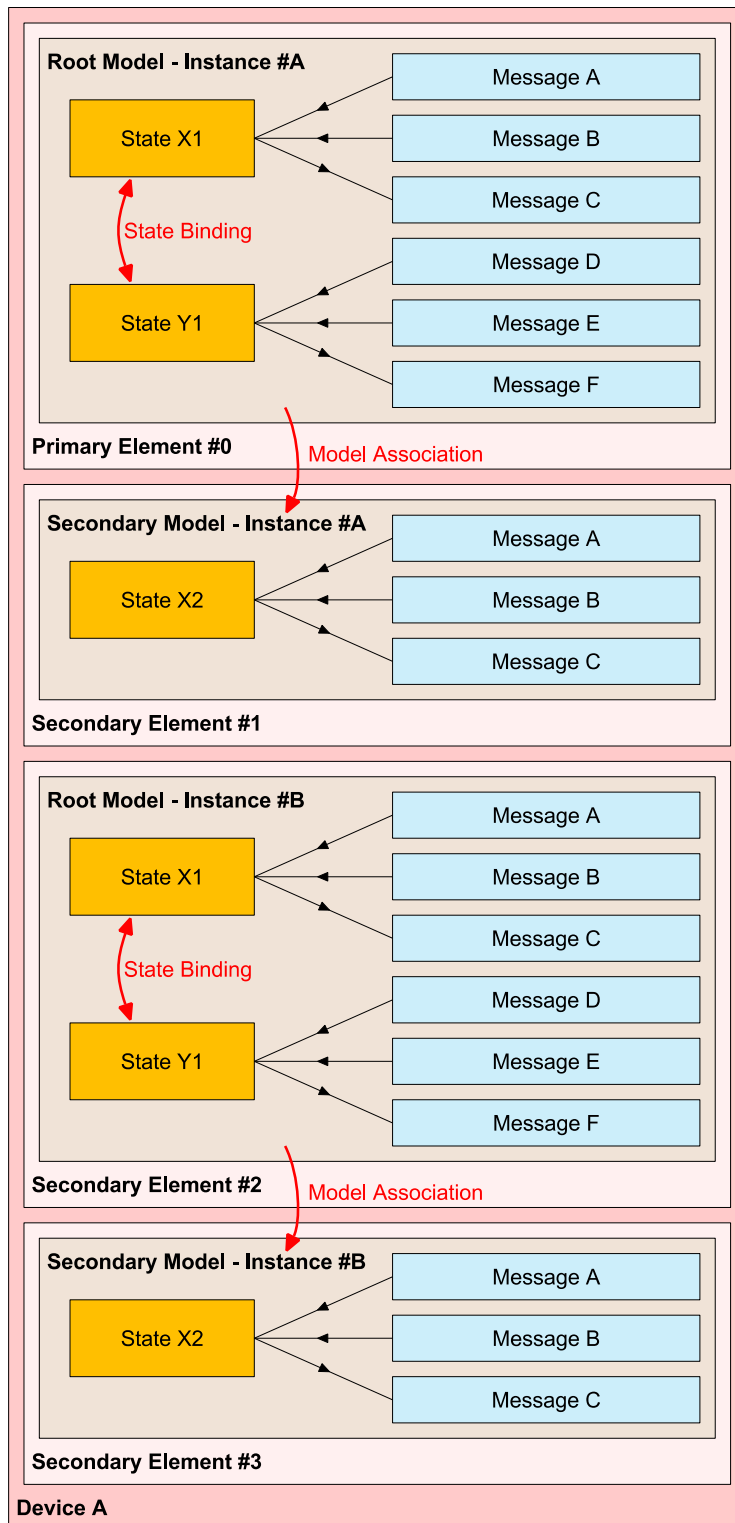


Figure 2.5: Element-model structure of a composite device

2.3.7 Example device

To help explain how the arrangement of models within elements determines the state and behavior of a device, we will use a dual-socket smart power strip device (shown in [Figure 2.6](#)) as an example. This device has a single radio that has the low energy feature of Bluetooth and two independent power sockets, each capable of controlling the power output. This example includes states, messages, and models defined in the Mesh Model specification [\[11\]](#).



Figure 2.6: Dual-socket smart power strip

The device has two elements (see [Section 2.3.4](#)) that represent each of the two power sockets. Each element has a unicast address assigned to it.

The functionality of each element is defined by the Generic Power Level Server model. The model defines a set of states on a server, as well as a set of messages that operate on the states.

A Generic Power Level Set message may be sent to the device to control the output power. The message is addressed to an element and carries the element's address in the Destination Address (DST) field (see [Section 2.3.8](#)).

The sockets can also be controlled by generic devices (such as a dimmer) that implement the Generic Level Client model (and do not know anything about power control). This model simply sets a desired level to zero, a maximum value, or a value in between. Power to the sockets is controlled through state binding. In each power socket, the Generic Power Actual state is bound to the Generic Level state. A Generic Level Client sends Generic Level messages to the Generic Level Server. The Generic Level state is changed, which in turn (via the defined binding) changes the Generic Power Actual state that controls the power output.

Elements can report states. In our example, each socket may report power level as well as the energy consumption of a device plugged into the socket. Energy consumption is reported using messages defined by the Sensor Server model. Each message has the element's address, which identifies the socket, in its SRC field (see [Section 3.4.4.6](#)).

[Figure 2.7](#) illustrates the element-model structure for the dual-socket device. Functionally, both elements of the device have identical features. The only difference is that the primary element handles the Configuration Server model, which is used for network management, in addition to the other models. Each element may have other models defined such as the Health Server model (see [Section 4.4.4](#)) or models defined in the Mesh Model specification [\[11\]](#).

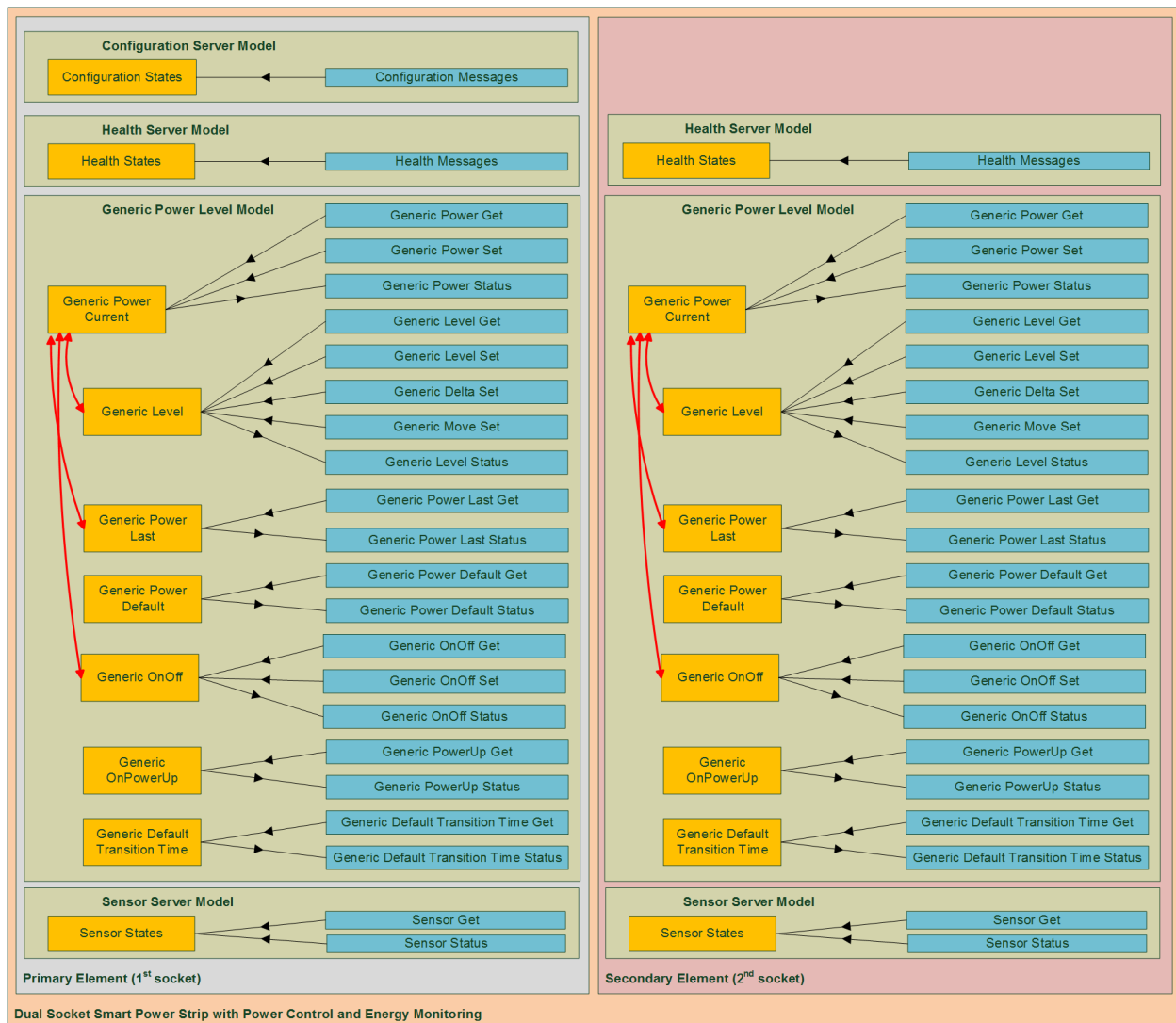


Figure 2.7: Element-model structure for the example device

2.3.8 Publish-subscribe and message exchange

Publication and subscription of data within the mesh network is described as using a publish-subscribe paradigm. Nodes that generate messages publish the messages to a unicast address, group address, or virtual address. Nodes that are interested in receiving the messages will subscribe to these addresses.

Generated messages are sent to destination mesh addresses that can be unicast, pre-configured group addresses, or virtual addresses. Messages can be sent as replies to other messages or can be unsolicited messages. When an instance of a model is sending a reply message, it uses the incoming message originator's source address as the destination address. When an instance of a model is sending unsolicited messages, it uses a model publish address as the destination address. Each instance of a model within a node has a single publish address.

On the receiving side, each instance of a model within a node can subscribe to one or more group addresses or virtual addresses. Whenever a message that is addressed to a group address or a virtual

address on one of the model's subscription lists arrives, it is processed by the node. A message is also processed when its destination address is the unicast address of a receiving element or when its destination address is a fixed group address that this device is a member of. If a node has multiple elements, then the message is processed once on each of the addressed elements.

Publish addresses and subscription lists for models defined by higher layer specifications use the Model Publication and Subscription List states that are managed by the Configuration Server Model.

A node can have multiple subscriptions per instance of a model's element, although nodes may limit the number of subscriptions that are supported. Using multiple subscription addresses allows a node to respond to messages that are published to different groups. For example, a light may be subscribed to messages sent to the bedside light group, the bedroom group, the upstairs group, and the house group.

Each message is sent from a single unicast address (an element address) and sequenced using a unique sequence number to facilitate detection of and protection against replay attacks.

2.3.9 Security

All messages are encrypted and authenticated using two types of keys. One key type is for the network layer communication, such that all communication within a mesh network would use the same network key. The other key type is for application data. Separating the keys for networking and applications allows sensitive access messages (e.g., for access control to a building) to be separated from non-sensitive access messages (e.g., for lighting). There are no unencrypted or unauthenticated messages within a mesh network.

2.3.9.1 Application and network security

Encrypting and authenticating messages at the upper transport layer and network layer is designed to secure communications within the mesh network against eavesdroppers and malicious attacks. Each layer maintains distinct keys to allow separation between application and network entities.

Splitting application keys from network keys enables secure relay transmission of application messages: Relay nodes can authenticate messages at network level without accessing the application data. For example, a light bulb acting as a Relay node should not be able to unlock doors.

This means that nodes can relay access messages using keys derived from the network key without having to know the application key; therefore they would not have the ability to change or understand the application data. It is expected that network keys would be widely known by many nodes within a network, thereby increasing the density of Relay nodes while protecting the different application areas from each other. This requires separate keys for each application. For example, the sensitive door security application would be separated from the non-sensitive doorbell and lighting application.

The application key is used directly along with an associated application key identifier that is used in certain contexts to identify the application used. However, the network key is always used through a key derivation function to generate other keys that are used directly. Examples of such keys include encryption and privacy keys. This allows a single network key to be changed and all the associated values that are derived from that key to be quickly derived. As with the application key, the network key is also used to derive a network key identifier (see Section 3.8.6).



The security model defines three separate keys (the device key (DevKey), the application key (AppKey), and the network key (NetKey)) to secure the messages. When a node is given a key, it is authorized to use that key. A key that is shared between multiple nodes enables any node with that key to transmit and receive messages using that key.

The device key facilitates confidentiality and authentication of key material between a Configuration Client and a single node. The application key facilitates confidentiality and authentication of application data sent between intended nodes. The network key facilitates privacy, confidentiality, and authenticity of network messages. A node may have knowledge of a single device key, multiple application keys, and multiple network keys.

A device key is similar to an application key in that it is designed to secure information sent by an application in the upper transport layer. However, a device key is only known by a Configuration Client and the single node. The Configuration Client knows the device keys for all nodes, which allows the Configuration Client to securely distribute keys to a set of nodes by sending these keys secured with the device key for each individual node, allowing a key distribution to be targeted at only those nodes that need to know. Use of a device key is designed to protect against the “trash-can” attack (a technique to retrieve information from a disposed device that can be used to carry out an attack on a network) by allowing the distribution of new network and application keys to selected devices only.

An application key can only be used with a single network key. This implies that a network key has one or more application keys associated with it. This association is known as the key binding.

The granularity of access layer security is on a per-model basis. Each server model has a set of application keys bound to it, defining the possible keys that should be used to encrypt and authenticate a message to be processed by the model. This allows multiple entities to operate certain node functions. Up to 251 application keys can be bound to a model. For example, a Light Lightness Server Model has three keys bound to it because the admin, user, and guest can all switch on a light. However, only the admin can configure the lamp, so the Configuration Server Model has only the admin application key bound to it.

2.3.9.2 Obfuscation

The network security model utilizes a privacy mechanism called obfuscation that utilizes AES to encrypt the source address, sequence numbers, and other header information using a privacy key. The intent for obfuscation is to make tracking nodes more difficult.

2.3.9.3 Network and application key identifiers

A node may have multiple network or application keys.

By using a key identifier, it is possible to identify which subset of keys are used to secure the message. For example, instead of checking 20 keys, a node may only need to check two keys that have the same least significant bits of the key identifier. If a message is received with a key identifier that is not known, then the node can immediately discard it.

The key identifier is generated from the network or application key using a key derivation function.

This specification defines a separate identifier for the network key and application key. A network key identifier is transmitted in each Network PDU using a 7-bit value, while the application key identifier is transmitted in each Lower Transport PDU using a 6-bit value.

2.3.9.4 Initialization vector index

A Network PDU contains a 24-bit sequence number that allows an element to transmit 16,777,216 Network PDUs. The sequence number is used in the security nonce to provide uniqueness; therefore the sequence number must not wrap. If an element is transmitting a new message at 2 Hz, then these sequence numbers would be exhausted after 97 days. To enable a mesh network to operate for longer periods of time than the sequence number space allows, an additional 4-octet value called the IV Index is defined that is included in the security nonce. For example, using the same 2 Hz message frequency would measure the lifetime of the network using the IV Index in billions of years.

To enable a gradual transition from one IV Index to the next, each Network PDU includes the least significant bit of the IV Index that was used to transmit the message. A node can also use an IV Update procedure to signal to peer nodes that it is updating the IV Index. This procedure takes a minimum of eight days to transition from the old IV Index to the new IV Index, thereby limiting the frequency that a node can transmit messages to 24 Hz. However, a node should not send more than 100 Network PDUs in any 10 second window, so this would typically take approximately 19 days to exhaust.

2.3.10 Friendship

Friendship is used by Low Power nodes to limit the amount of time that they need to listen. If a node cannot receive continuously, then it is possible that it will not receive mesh messages that it should be processing. This includes security updates required for maintaining the security of the network as well as the normal mesh messages.

If the Low Power node does not receive such messages, then it may not operate as desired and it may also fail to keep up-to-date with the latest security state of the network and eventually drop off the network if this security is changed without its knowledge.

Friendship is a special relationship between a Low Power node and one neighboring Friend node. These nodes must be within a single hop of each other and in the same subnet.

Friendship is first established and initiated by the Low Power node; once established, the Friend node performs a number of actions that help reduce the power consumption on the Low Power node. The Friend node maintains a Friend Queue for the Low Power node, which stores all incoming messages addressed to the Low Power node. The Friend node delivers those messages to the Low Power node when requested by the Low Power node. Also, the Friend node delivers security updates to the Low Power node.

When friendship is established between a Low Power node and one Friend node, the two nodes are considered to be “friends”.

A Friend node may be friends with multiple Low Power nodes. A Low Power node can only be friends with a single Friend node.

An example topology of a mesh network illustrating Friend nodes and Low Power nodes is shown and described in Section 2.3.12.



2.3.11 Features

The functionality of nodes is determined by the features that they support. All nodes have the ability to transmit and receive mesh messages. Nodes can also optionally support one or more additional features:

- Relay feature – the ability to receive and retransmit mesh messages over the advertising bearer to enable larger networks.
- Proxy feature – the ability to receive and retransmit mesh messages between GATT and advertising bearers.
- Low Power feature – the ability to operate within a mesh network at significantly reduced receiver duty cycles only in conjunction with a node supporting the Friend feature.
- Friend feature – the ability to help a node supporting the Low Power feature to operate by storing messages destined for those nodes.

A node that supports a feature may have that feature enabled or disabled, and the feature, when enabled, may be or may not be in use.

A node supporting the Relay feature may have this feature disabled, but it would still support the Relay feature, it is just that it is not performing the functionality required by that feature. A node that supports the Relay feature and has the Relay feature enabled is known as a Relay node.

A node supporting the Proxy feature may have this feature disabled, but it would still support the Proxy feature, it is just that it is not performing the functionality required by that feature. A node that supports the Proxy feature and has the Proxy feature enabled is known as a Proxy node.

A node supporting the Low Power feature cannot have this feature disabled and must establish a friendship with another node supporting the Friend feature before it can use the Low Power feature to reduce receiver duty cycles. A node that supports the Low Power feature and has a friendship with a node that supports the Friend feature is known as a Low Power node.

A node supporting the Friend feature may have this feature disabled, but it would still support the Friend feature, it is just that it is not performing the functionality required by that feature. A node that supports the Friend feature, has the Friend feature enabled, and has a friendship with a node that supports the Low Power feature is known as a Friend node.

2.3.12 Topology

Nodes that support the various features described above can be formed into a mesh network. An illustration of a mesh network is shown in Figure 2.8 below.

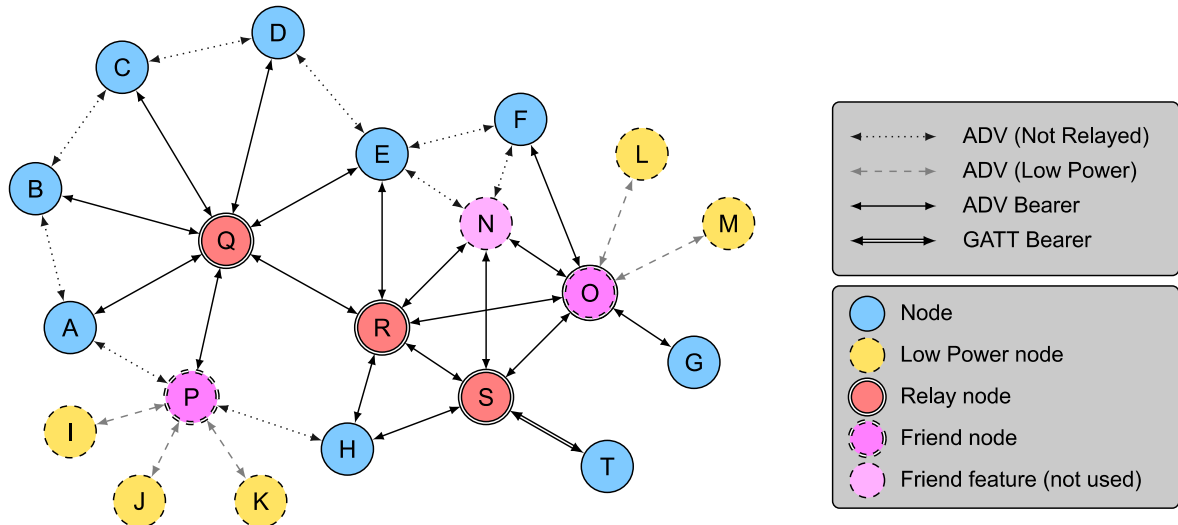


Figure 2.8: Example Topology of a mesh network

Figure 2.8 shows three Relay nodes: Q, R, and S. The three nodes that support the Friend feature are N, O, and P, however N does not have any friendships; therefore only O and P are Friend nodes. There are five Low Power nodes: I, J, K, L, and M. Nodes I, J, and K have P as their friend, while L and M have O as their friend. Node T is only connected to the mesh network using a GATT bearer; therefore S must relay all messages to and from T.

For example, if a message is to be sent from T to L, then T will send the message to node S using the GATT bearer. Node S will retransmit this message using the advertising bearer. Nodes H, R, N, and O are within radio range of node S; therefore they will receive this message. Node O, being the friend of node L will store the message, and if the message was a segmented message, node O will respond with an acknowledgment at the lower transport layer. Sometime later, L will poll node O to check for new messages, such that O will forward the message originally sent by T to L.

2.4 Mesh gateway

A mesh gateway is a node that is able to translate messages between the mesh network and a non-Bluetooth technology. A node may be able to send and receive mesh messages through a mesh gateway while not in the range of any of the Relay nodes. This translation is out of scope for this specification.

2.5 Concurrency limitations and restrictions

There are no concurrency limitations or restrictions for nodes imposed by this specification.

2.6 Topology limitations and restrictions

There are no topology limitations or restrictions imposed by this specification when used with the Bluetooth low energy transport.

3 Mesh networking

This section is structured as in the layered architecture that is described in Section 2.1. In addition, there are sections on mesh security and mesh network management.

3.1 Conventions

The following conventions apply to this specification.

3.1.1 Endianness and field ordering

For the network layer, lower transport layer, upper transport layer, mesh beacons, and Provisioning, all multiple-octet numeric values shall be sent in big endian, as described in Section 3.1.1.1.

For the access layer and Foundation Models, all multiple-octet numeric values shall be little endian as described in Section 3.1.1.2.

Where network data structures are made of multiple fields, the fields are listed in the tables from top to bottom and they appear in the corresponding figures from left to right (i.e., the top row of the table corresponds to the left of the figure). Table 3.1 shows an example data structure made up of multiple fields.

Field	Size (bits)	Field Content Description
Field 0	4	The start of this field is in Octet 0 (left most octet in corresponding figure)
Field 1	12	The start of this field is in Octet 0 and ends in Octet 1
Field 2	16	The start of this field is in Octet 2 and ends in Octet 3

Table 3.1: Field ordering example

In order to convert the data structure defined in a table into a series of octets in the layer that uses big endian the following procedure is used. The binary number with N unassigned bits is created. The number of bits N in the number is equal to the sum of the number of bits of every field in the table. The most significant bits (MSb) of the number are set to the value of Field 0 (first row of the table), then the number's unassigned MSbs are set to the value of Field 1. This procedure is continued for consecutive fields of the table and ends when least significant bits (LSb) of the number are set to value of last field of the table. As a final step the number is transmitted in big endian form (i.e., most significant octet first). This is illustrated in Figure 3.1.

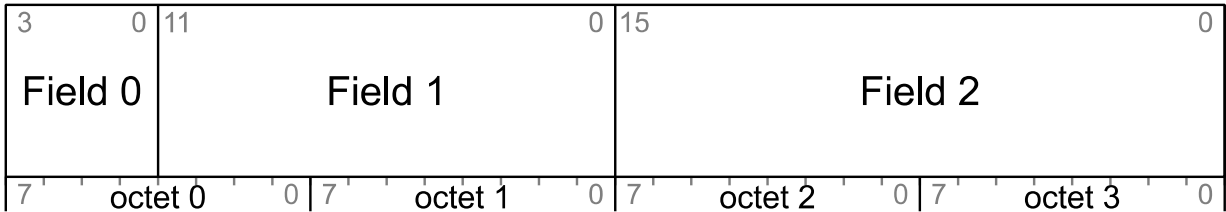


Figure 3.1: Field ordering example: big endian



For example, the field 0 is 4 bits wide and has value of 0x6, field 1 is 12 bits wide and has value 0x987, and field 2 is 16 bits wide and has value of 0x1234. The value of the binary number is 0x69871234 and shall be transmitted as 0x69, 0x87, 0x12, 0x34.

In order to convert the data structure defined in a table into a series of octets in the layer that uses little endian the following procedure is used. The binary number with N unassigned bits is created. The number of bits N in the number is equal to the sum of the number of bits of every field in the table. The LSbs of the number are set to the value of Field 0 (first row of the table), then the number's unassigned LSbs are set to the value of Field 1. This procedure is continued for consecutive fields of the table and ends when MSBs of the number are set to the value of last field of the table. As a final step the number is transmitted in little endian form (i.e., least significant octet first). This is illustrated in [Figure 3.2](#).

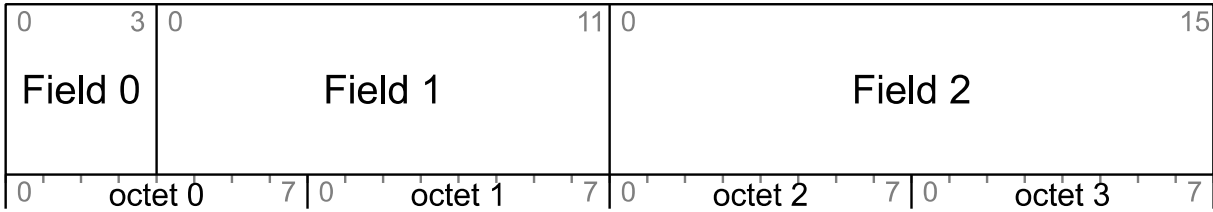


Figure 3.2: Field ordering example: little endian

For example, the field 0 is 4 bits wide and has a value of 0x6, field 1 is 12 bits wide and has a value of 0x987, and field 2 is 16 bits wide and has a value of 0x1234. The value of the binary number is 0x12349876 and shall be transmitted as 0x76, 0x98, 0x 34, 0x12.

3.1.1.1 Big endian

When multiple-octet values are defined as sent in “big endian” (also known as “network byte order”), the conventions in this section apply. For example, the value 0x123456 shall be transmitted as 0x12, 0x34, and 0x56 (most significant octet first).

3.1.1.2 Little endian

When multiple-octet values are defined as sent in “little endian”, the conventions in this section apply. For example, the value 0x123456 shall be transmitted as 0x56, 0x34, and 0x12 (least significant octet first).

3.2 Features

This specification defines four optional features:

- Relay feature (see Section [3.4.6.1](#))
- Proxy feature (see Section [3.4.6.2](#))
- Friend feature (see Section [3.6.6.3](#))
- Low Power feature (see Section [3.6.6.4](#))



3.3 Bearers

This specification defines two mesh bearers over which mesh messages may be transported:

- An advertising bearer (see Section 3.3.1)
- A GATT bearer (see Section 3.3.2)

A node shall support the advertising bearer or the GATT bearer or both.

3.3.1 Advertising bearer

When using the advertising bearer, a mesh packet shall be sent in the Advertising Data of a Bluetooth Low Energy advertising PDU using the Mesh Message AD Type identified by «Mesh Message» as defined in [4]. The Mesh Message AD Type contains a Network PDU as defined in Table 3.2.

Length	AD Type	Contents
0xXX	«Mesh Message»	Network PDU

Table 3.2: Mesh Message AD Type

Any advertisement using the Mesh Message AD Type shall be non-connectable and non-scannable undirected advertising events. If a node receives a Mesh Message AD Type in a connectable advertisement or scannable advertising event, the message shall be ignored.

Note: Non-connectable advertisements are used since there is no need to include the Flags AD Type in the advertising packets, thereby enabling two additional octets to be allocated to the Network PDU (see [7]). To lower the probability of packet collisions on all advertising channels, it is recommended to randomize the gap between consecutive packets within an Advertising Event (see [1]).

A device supporting only the advertising bearer should perform passive scanning with a duty cycle as close to 100 percent as possible in order to avoid missing any incoming mesh messages or Provisioning PDUs.

All devices shall support both the GAP Observer role and GAP Broadcaster role.

3.3.2 GATT bearer

The GATT bearer is provided to enable devices that are not capable of supporting the advertising bearer to participate in a mesh network. The GATT bearer uses the Proxy protocol (see Section 6) to transmit and receive Proxy PDUs between two devices over a GATT connection.

The GATT bearer uses a characteristic to write to and receive notifications of mesh messages using the attribute protocol.

The GATT bearer defines two roles: a GATT Bearer Client and a GATT Bearer Server.

The GATT Bearer Client shall be a GATT Client. The GATT Bearer Server shall be a GATT Server.

The GATT Bearer Server shall instantiate one and only one Mesh Proxy Service, as defined in Section 7.2.

The GATT Bearer Client shall support the Mesh Proxy Service.



The GATT Bearer Client shall perform primary service discovery using either the GATT *Discover All Primary Services* sub-procedure or the GATT *Discover Primary Services by Service UUID* sub-procedure to discover the Mesh Proxy Service.

As required by GATT, the GATT Bearer Client must be tolerant of additional optional characteristics in the service records of services used with this profile.

The GATT Bearer Client shall use either the GATT *Discover All Characteristics of a Service* sub-procedure or the GATT *Discover Characteristics by UUID* sub-procedure to discover the characteristics of the service.

The GATT Bearer Client shall use the GATT *Discover All Characteristic Descriptors* sub-procedure to discover the characteristic descriptors, which are described in the following sections.

The GATT Bearer Client shall discover the Mesh Proxy Data In characteristic, Mesh Proxy Data Out characteristic and its *Client Characteristic Configuration* descriptor. Once the *Client Characteristic Configuration* descriptor has been discovered, it shall enable notifications using this characteristic.

To send a Proxy PDU (see Section 6.3), the GATT Bearer Client shall use the *Write Without Response* sub-procedure to write the Proxy PDU to the GATT Bearer Server by writing to the Mesh Proxy Data In characteristic.

To receive a Proxy PDU, the GATT Bearer Client shall be able to receive multiple notifications of the Mesh Proxy Data Out characteristic. Each notification contains a single Proxy PDU.

3.4 Network layer

The network layer defines the Network PDU format that allows Lower Transport PDUs to be transported by the bearer layer. It decrypts and authenticates and forwards incoming messages received on input interfaces to upper layers and/or output interfaces and encrypts and authenticates and forwards outgoing messages delivering them to output network interfaces.

3.4.1 Endianness

All multiple-octet numeric values in this layer shall be sent in “big endian”, as described in Section 3.1.1.1.

3.4.2 Addresses

The network layer defines four basic types of addresses: unassigned, unicast, virtual, and group.

Addresses are 16 bits in length and are encoded as defined in Table 3.3 below.

Values	Address Type
0b0000000000000000	Unassigned Address
0b0xxxxxxxxxxxxxx (excluding 0b0000000000000000)	Unicast Address
0b10xxxxxxxxxxxxxx	Virtual Address
0b11xxxxxxxxxxxxxx	Group Address

Table 3.3: 16-bit address allocations



3.4.2.1 Unassigned address

An unassigned address is an address in which the element of a node has not been configured yet or no address has been allocated. The unassigned address shall have the value 0x0000 as shown in [Figure 3.3](#) below. This may be used, for example, to disable message publishing of a model by setting the publish address of a model to the unassigned address.

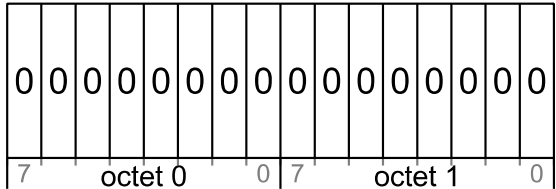


Figure 3.3: Unassigned address format

An unassigned address shall not be used in a source or destination address field of a message.

3.4.2.2 Unicast address

A unicast address is a unique address allocated to each element. A unicast address has bit 15 set to 0. The unicast address shall not have the value 0x0000, and therefore can have any value from 0x0001 to 0x7FFF inclusive as shown in [Figure 3.4](#) below.

A unicast address is allocated to each element of a node for the lifetime of the node on the network by a Provisioner during provisioning as described in [Section 5.4.2.5](#). The address may be unallocated by a Provisioner to allow the address to be reused using the procedure defined in [Section 3.10.7](#).

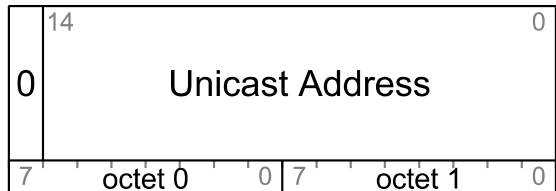


Figure 3.4: Unicast address format

A unicast address shall be used in the source address field of a message and may be used in the destination address field of a message. A message sent to a unicast address shall be processed by at most one element.

3.4.2.3 Virtual address

A virtual address represents a set of destination addresses. Each virtual address logically represents a Label UUID, which is a 128-bit value that does not have to be managed centrally. One or more elements may be programmed to publish or subscribe to a Label UUID. The Label UUID is not transmitted and shall be used as the Additional Data field of the message integrity check value in the upper transport layer (see [Section 3.8.7.1](#)).

The virtual address is a 16-bit value that has bit 15 set to 1, bit 14 set to 0, and bits 13 to 0 set to the value of a hash. This hash is a derivation of the Label UUID such that each hash represents many Label UUIDs.

$SALT = s1$ ("vtad")

$hash = AES-CMAC_{SALT}(Label\ UUID) \bmod 2^{14}$

When an Access message is received to a virtual address that has a matching hash, each corresponding Label UUID is used by the upper transport layer as additional data as part of the authentication of the message until a match is found.

Control messages cannot use virtual addresses.

Label UUIDs may be generated randomly as defined in [8]. A Configuration Client may assign and track virtual addresses, however two devices can also create a virtual address using some out-of-band (OOB) mechanism. Unlike group addresses, these could be agreed upon by the devices involved and would not need to be registered in the centralized provisioning database, as they are unlikely to be duplicated.

A disadvantage of virtual addresses is that a multi-segment message is required to transfer a Label UUID to a publishing or subscribing node during configuration.

A virtual address can have any value from 0x8000 to 0xBFFF as shown in Figure 3.5 below.

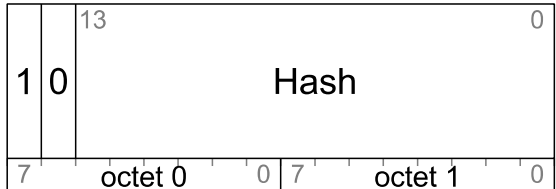


Figure 3.5: Virtual address format

Note: When factoring in a 32-bit MIC and the size of the hash, there is only a $1/246 = 1.42 \times 10^{-14}$ likelihood that two matching virtual addresses using the same application key but different Label UUIDs will collide.

3.4.2.4 Group address

A group address is an address that is programmed into zero or more elements. A group address has bit 15 set to 1 and bit 14 set to 1., as shown in Figure 3.6 below. Group addresses in the range 0xFF00 through 0xFFFF are reserved for Fixed Group addresses (see Table 3.4), and addresses in the range 0xC000 through 0xFEFF are generally available for other usage.

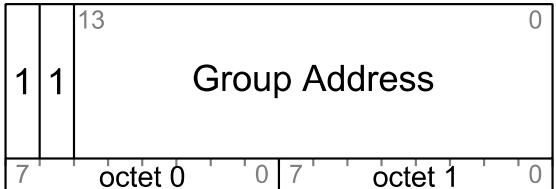


Figure 3.6: Group address format



A group address shall only be used in the destination address field of a message. A message sent to a group address shall be delivered to all the instances of models that subscribe to this group address.

There are two types of group address; those that can be assigned dynamically and those that are fixed. The fixed group addresses are defined in [Table 3.4](#) below.

Values	Fixed Group Address Name
0xFF00–0xFFFB	RFU
0xFFFC	all-proxies
0xFFFD	all-friends
0xFFFE	all-relays
0xFFFF	all-nodes

Table 3.4: Fixed group addresses

A message sent to the all-proxies address shall be processed by the primary element of all nodes that have the proxy functionality enabled.

A message sent to the all-friends address shall be processed by the primary element of all nodes that have the friend functionality enabled.

A message sent to the all-relays address shall be processed by the primary element of all nodes that have the relay functionality enabled.

A message sent to the all-nodes address shall be processed by the primary element of all nodes.

3.4.3 Address validity

[Table 3.5](#) shows which address types are valid for use in the Source Address field and the Destination Address field.

Address Type	Valid in Source Address Field	Valid in Destination Address Field	
		Segmented and Unsegmented Control Messages (see Section 3.5.2)	Segmented and Unsegmented Access Messages (see Section 3.5.2)
Unassigned Address	No	No	No
Unicast Address	Yes	Yes	Yes
Virtual Address	No	No	Yes
Group Address	No	Yes	Yes

Table 3.5: Address type and message field validity

[Table 3.6](#) shows which address types are valid for use with device keys and application keys.



Address Type	Valid with Device Key	Valid with Application Key
Unassigned Address	No	No
Unicast Address	Yes	Yes
Virtual Address	No	Yes
Group Address	No	Yes

Table 3.6: Address type and access layer key type validity

3.4.4 Network PDU

The mesh Network PDU format is defined in Table 3.7 and illustrated in Figure 3.7 below:

Field Name	Bits	Notes
IVI	1	Least significant bit of IV Index
NID	7	Value derived from the NetKey used to identify the Encryption Key and Privacy Key used to secure this PDU
CTL	1	Network Control
TTL	7	Time To Live
SEQ	24	Sequence Number
SRC	16	Source Address
DST	16	Destination Address
TransportPDU	8 to 128	Transport Protocol Data Unit
NetMIC	32 or 64	Message Integrity Check for Network

Table 3.7: Network PDU field definitions

Network PDUs are secured using keys derived from a single network key, as identified by the NID field.

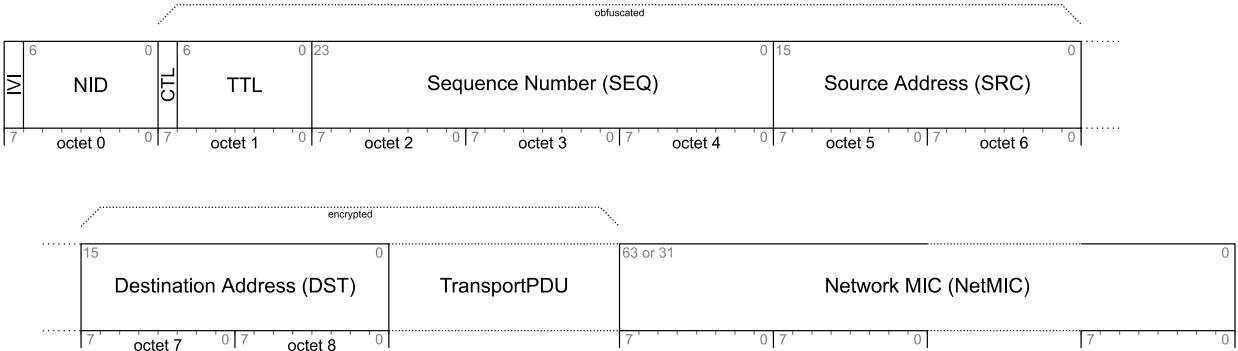


Figure 3.7: Network PDU format

3.4.4.1 IVI

The IVI field contains the least significant bit of the IV Index used in the nonce to authenticate and encrypt this Network PDU (see Section 3.8.3).

3.4.4.2 NID

The NID field contains a 7-bit network identifier that allows for an easier lookup of the Encryption Key and Privacy Key used to authenticate and encrypt this Network PDU (see Section 3.8.6.3.1).

The NID value is derived from the network key in conjunction with the Encryption Key and Privacy Key. It is derived differently for main network messages and for private network messages between a Friend and its Low Power node (see Section 3.8.6.3.1).

3.4.4.3 CTL

The CTL field is a 1-bit value that is used to determine if the message is part of a Control Message or an Access Message, as illustrated in Table 3.8.

If the CTL field is set to 0, the NetMIC is a 32-bit value and the Lower Transport PDU contains an Access Message.

If the CTL field is set to 1, the NetMIC is a 64-bit value and the Lower Transport PDU contains a Control Message.

CTL Field	Message Type	NetMIC Size (bits)
0	Access Message	32
1	Control Message	64

Table 3.8: CTL field message types and NetMIC sizes

3.4.4.4 TTL

The TTL field is a 7-bit field. The following values are defined:

- 0 = has not been relayed and will not be relayed
- 1 = may have been relayed, but will not be relayed
- 2 to 126 = may have been relayed and can be relayed
- 127 = has not been relayed and can be relayed

The initial value of this field is set by the transmitting layer (lower transport layer, upper transport layer, access, foundation model, model) or an application and used by the network layer when operating as a Relay node.

The use of the TTL value of zero allows a node to transmit a Network PDU that it knows will not be relayed, and therefore the receiving node can determine that the sending node is a single radio link away. The use of a TTL value of one or larger cannot be used for such a determination.

3.4.4.5 SEQ

The SEQ field is a 24-bit integer. The combined SEQ field, IV Index field, and SRC field (see Section 3.4.4.6) shall be a unique value for each new Network PDU that this element originates.

3.4.4.6 SRC

The SRC field is a 16-bit value that identifies the element that originated this Network PDU. This address shall be a unicast address.

The SRC field is set by the originating element and untouched by nodes operating as a Relay node.

3.4.4.7 DST

The DST field is a 16-bit value that identifies the element or elements that this Network PDU is directed towards. This address shall be a unicast address, a group address, or a virtual address.

The DST field is set by the originating node and is untouched by the network layer in nodes operating as a Relay node.

3.4.4.8 TransportPDU

The TransportPDU field, from a network layer point of view, is a sequence of octets of data. When the CTL bit is 0, the TransportPDU field shall be a maximum of 128 bits. When the CTL bit is 1, the TransportPDU field shall be a maximum of 96 bits.

The TransportPDU field is set by the originating lower transport layer and shall not be changed by the network layer.

3.4.4.9 NetMIC

The NetMIC field is a 32-bit or 64-bit field (depending on the value of the CTL bit) that authenticates that the DST and TransportPDU have not been changed.

When the CTL bit is 0, the NetMIC field shall be 32 bits. When the CTL bit is 1, the NetMIC field shall be 64 bits.

The NetMIC is set by the network layer at each node that transmits or relays this Network PDU.

3.4.5 Network interfaces

The network layer supports sending and receiving messages via multiple bearers. Multiple instances of a bearer may be present. Each instance of a bearer is connected to the network layer via a network interface. To allow sending messages between elements within the same node the local interface is used.

For example, a node may have three interfaces: one used to send and receive messages via an advertising bearer and two interfaces to a GATT bearer, one for each client connected via a GATT connection.

Interfaces provide input and output filters. Filters may be configured using bearer-specific PDUs or internally by services exposed on a node, such as the Mesh Proxy Service (see Section 7.2).

3.4.5.1 Interface input filter

Interface input filter decides if an incoming Mesh message is delivered to the network layer for further processing or if it is dropped.

3.4.5.2 Interface output filter

Interface output filter decides if an outgoing Mesh message is delivered to a bearer or if it is dropped.

The output filter of the interface connected to advertising or GATT bearers shall drop all messages with TTL value set to 1.

3.4.5.3 Local Network Interface

A Local Network Interface allows sending messages between elements within the same node.

A node shall implement a Local Network Interface.

Upon receiving a message by a Local Network Interface, the message shall be delivered to all elements of the node.

3.4.5.4 Advertising Bearer Network Interface

The Advertising Bearer Network Interface allows sending messages using the advertising bearer (see Section 3.3.1).

Upon receiving a Network PDU that is not tagged as relay from the network layer, the Advertising Bearer Network Interface shall retransmit the Network PDU over the advertising bearer using the value of the Network Transmit state (see Section 4.2.19).

Upon receiving a Network PDU that is tagged as relay from the network layer, the Advertising Bearer Network Interface shall retransmit the Network PDU over the advertising bearer using the value of the Relay Retransmit state (see Section 4.2.20).

3.4.6 Network layer behavior

3.4.6.1 Relay feature

The Relay feature is used to relay/forward Network PDUs received by a node over the advertising bearer. This feature is optional and if supported can be enabled and disabled. If the Proxy feature is supported, then both GATT and advertising bearers shall be supported.

3.4.6.2 Proxy feature

The Proxy feature is used to relay/forward Network PDUs received by a node between GATT and advertising bearers. This feature is optional and if supported can be enabled and disabled. When this feature is supported, the Mesh Proxy Service (see Section 7.2) shall be exposed.

3.4.6.3 Receiving a Network PDU

A message is delivered from a bearer to the network layer via a network interface. The interface shall apply filtering rules defined by its input filter (see Section 3.4.5.1). If the message passes the input filter, it is delivered to the network layer for further processing.

Each Network PDU that is received can be tagged with additional metadata that can be used later to change the processing of this message.

Upon receiving a message, the node shall check if the value of the NID field value matches one or more known NIDs. If the NID field value does not match a known NID, then the message shall be ignored. If the NID field value matches a known NID, the node shall authenticate the message against each known network key that matched. If the message does not authenticate against any known network key, then the message shall be ignored. If the message does authenticate against a network key, the SRC and DST fields are considered valid (see Section 3.4.3), and the message is not in the Network Message Cache (see Section 3.4.6.5), then the message shall be processed by the lower transport layer.

When a message is retransmitted, as defined below, the IV Index used when retransmitting the message shall be the same as the IV Index when it was received.

If the message delivered from the advertising bearer is processed by the lower transport layer, the Relay feature is supported and enabled, the TTL field has a value of 2 or greater, and the destination is not a unicast address of an element on this node, then the TTL field value shall be decremented by 1, the Network PDU shall be tagged as relay, and the Network PDU shall be retransmitted to all network interfaces connected to the advertising bearer. It is recommended that a small random delay is introduced between receiving a Network PDU and relaying a Network PDU to avoid collisions between multiple relays that have received the Network PDU at the same time.

If the message delivered from the GATT bearer is processed by the lower transport layer, and the Proxy feature is supported and enabled, and the TTL field has a value of 2 or greater, and the destination is not a unicast address of an element on this node, then the TTL field value shall be decremented by 1, and the Network PDU shall be retransmitted to all network interfaces.

If the message delivered from the advertising bearer is processed by the lower transport layer, and the Proxy feature is supported and enabled, and the TTL field has a value of 2 or greater, and the destination is not a unicast address of an element on this node, then the TTL field shall be decremented by 1 and the Network PDU shall be retransmitted to all network interfaces connected to the GATT bearer.

Figure 3.8 illustrates an example of processing steps for an incoming Network PDU:



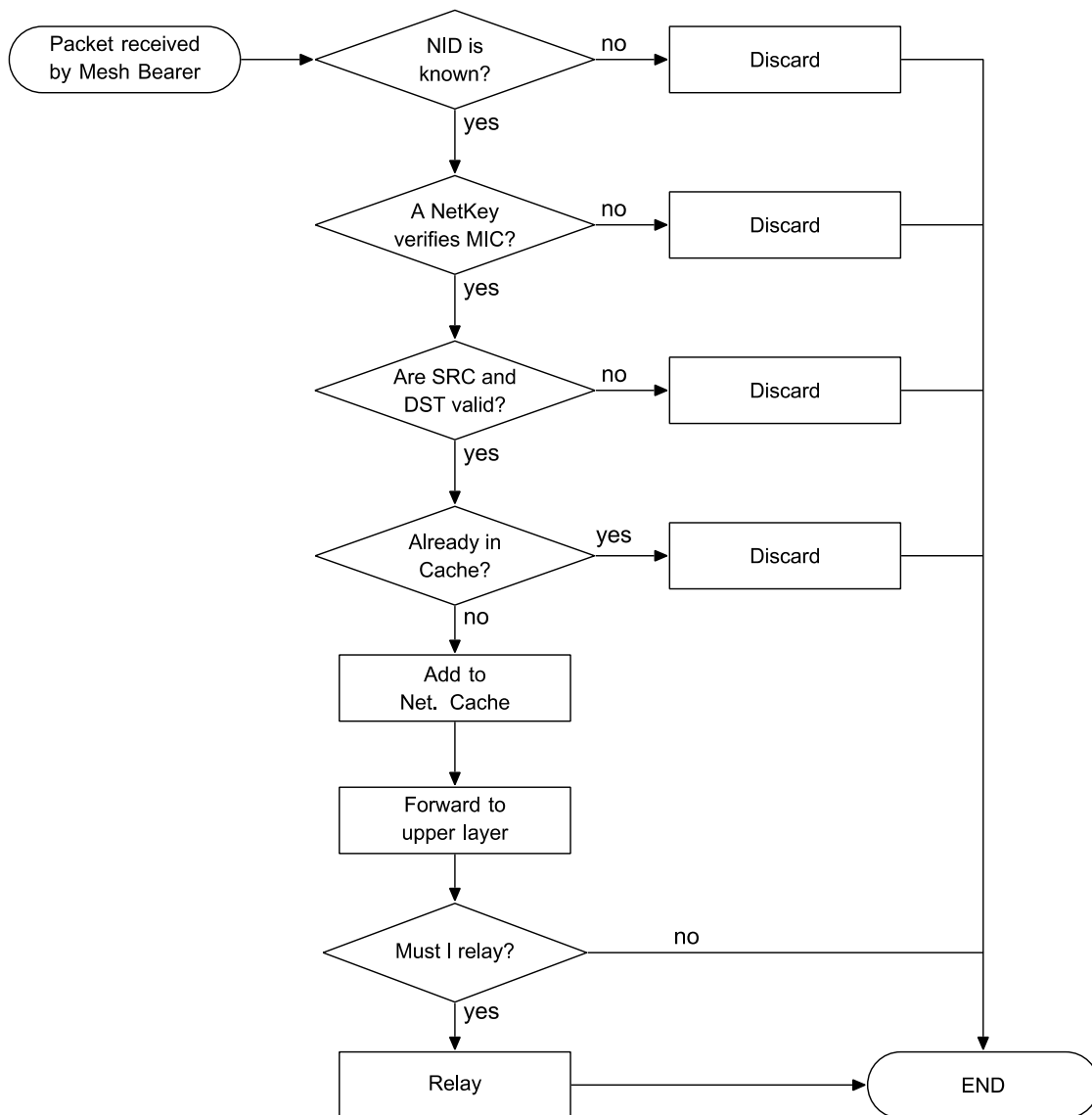


Figure 3.8: Example of Network PDU processing steps

3.4.6.4 Transmitting a Network PDU

Messages are transmitted by an element in the context of a mesh subnet, which is identified by a unique network key.

The IVI field shall be set to the least significant bit of the IV Index value being used to transmit for the mesh subnet.

The NID field shall be set to the NID value associated with the Encryption Key and Privacy Key used for encryption and obfuscation.

The CTL field shall be set by a higher layer.

The TTL field shall be set by a higher layer.

The SEQ field shall be set by the network layer to the sequence number of the element. The sequence number shall then be incremented by one for every new Network PDU.

The SRC field shall be set by the network layer to the unicast address of the element that is sending this Network PDU.

The DST field shall be set to a unicast address, a group address, or a virtual address to identify the destination element or elements and shall be set by the lower transport, upper transport, or access layer.

The TransportPDU field shall be set by a higher layer.

The NetMIC field shall be set as defined in Section 3.8.7.2.

The message shall be delivered to all network interfaces. Each interface shall apply filtering rules defined by its output filter (see Section 3.4.5.2). If the Network PDU passes the output filter, it shall be transmitted on a bearer.

3.4.6.5 Network Message Cache

In order to reduce unnecessary security checks and excessive relaying, a node shall include a Network Message Cache of all recently seen Network PDUs. If a Network PDU is received that is already in the Network Message Cache, then the Network PDU shall not be processed (i.e., it shall be immediately discarded). If a Network PDU is received and that Network PDU is not in the Network Message Cache, then the Network PDU can be processed (e.g., checked against network security), and if it is a valid Network PDU, it shall be stored in the Network Message Cache.

The node is not required to cache the entire Network PDU and may cache only part of it for tracking, such as values for NetMIC, SRC/SEQ or others. However, this is left to the implementation as long as the condition of not processing the same Network PDU more than once is achieved within the limits of the device capabilities.

When the Network Message Cache is full and an incoming new Network PDU needs to be cached, an incoming new Network PDU shall replace the oldest Network PDU that is already in the Network Message Cache.

The Network Message Cache shall be able to store at least two Network PDUs, although it is highly recommended to have a Network Message Cache size appropriate to the anticipated network density. The details of the incoming message processing procedure are left to the implementation.

3.5 Lower transport layer

The lower transport layer takes an Upper Transport PDU from the upper transport layer and transmits those messages to a peer lower transport layer. These Upper Transport PDUs may fit into a single Lower Transport PDU, or may be segmented into multiple Lower Transport PDUs. Upon receiving messages, the lower transport layer processes Lower Transport PDUs, reassembling Upper Transport PDUs from possibly multiple PDUs and sending these up to the upper transport layer once reassembly is complete.



3.5.1 Endianness

All multiple-octet numeric values in this layer shall be sent in “big endian”, as described in Section 3.1.1.1.

3.5.2 Lower Transport PDU

The Lower Transport PDU is used to transmit Upper Transport PDUs to another node.

The most significant bit of the first octet of the Lower Transport PDU is the SEG field, which is used to determine if the Lower Transport PDU is formatted as a segmented or unsegmented message.

There are four formats used, depending on the value of the CTL field in the Network PDU and the SEG field in the Lower Transport PDU as defined in Table 3.9 below.

CTL Field	SEG Field	Lower Transport PDU Format
0	0	Unsegmented Access Message
0	1	Segmented Access Message
1	0	Unsegmented Control Message
1	1	Segmented Control Message

Table 3.9: Lower Transport PDU format types

3.5.2.1 Unsegmented Access message

The Unsegmented Access message is used to transport an Upper Transport Access PDU that fits into a single Network PDU. Figure 3.9 shows an illustration of an Unsegmented Access message, and Table 3.10 shows the fields for this message.

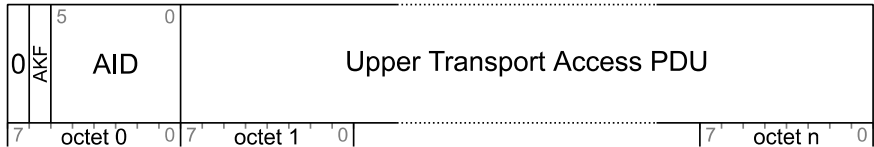


Figure 3.9: Unsegmented Access message

Field	Size (bits)	Notes
SEG	1	0 = Unsegmented Message
AKF	1	Application Key Flag
AID	6	Application key identifier
Upper Transport Access PDU	40 to 120	The Upper Transport Access PDU

Table 3.10: Unsegmented Access message format

The SEG field shall be set to 0.



The AKF and AID fields shall be set by the upper transport layer according to the application key or device key used to encrypt the access payload (see Section 3.6.4.1).

The Upper Transport Access PDU is supplied by the upper transport layer.

This message does not have a SZMIC field. The TransMIC in the upper transport layer shall be a 32-bit value, as if the SZMIC field has the value 0.

3.5.2.2 Segmented Access message

The Segmented Access message is used to transport a segment of an Upper Transport Access PDU. Figure 3.10 shows an illustration of a Segmented Access message, and Table 3.11 shows the fields for this message.

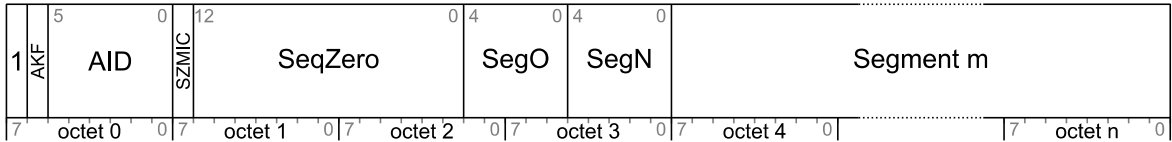


Figure 3.10: Segmented Access message

Field	Size (bits)	Notes
SEG	1	1 = Segmented Message
AKF	1	Application Key Flag
AID	6	Application key identifier
SZMIC	1	Size of TransMIC
SeqZero	13	Least significant bits of SeqAuth
SeqO	5	Segment Offset number
SeqN	5	Last Segment number
Segment m	8 to 96	Segment m of the Upper Transport Access PDU

Table 3.11: Segmented Access message format

The SEG field shall be set to 1.

The SZMIC field indicates the size of the TransMIC in the Upper Transport Access PDU. If the SZMIC field is set to 0, the TransMIC is a 32-bit value. If the SZMIC field is set to 1, the TransMIC is a 64-bit value.

The AKF and AID fields shall be set by the upper transport layer according to the application key or device key used to encrypt the access payload (see Section 3.6.4.1).

The SeqZero field shall be set by the upper transport layer.

The SeqO field shall be set to the segment number (zero-based) of the segment m of this Upper Transport PDU.

The SeqN field shall be set to the last segment number (zero-based) of this Upper Transport PDU.



The Segment m field, with the segment number m , shall be set to the subset of octets from the Upper Transport Access PDU. For all segments except the last segment, Segment m shall be octets $12*m$ to $12*m+11$. In the last segment, Segment m shall be $12*m$ through the end of the message.

Every Segmented Access message for the same Upper Transport Access PDU shall have the same values for AKF, AID, SZMIC, SeqZero, and SegN.

3.5.2.3 Unsegmented Control Message

The Unsegmented Control Message is used to transport either a Segment Acknowledgment message or a Transport Control message. Figure 3.11 shows an illustration of an Unsegmented Control message, and Table 3.12 shows the fields for this message.

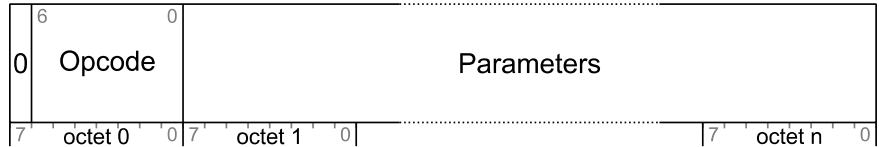


Figure 3.11: Unsegmented Control message

Field	Size (bits)	Notes
SEG	1	0 = Unsegmented Message
Opcode	7	0x00 = Segment Acknowledgment 0x01 to 0x7F = Opcode of the Transport Control message
Parameters	0 to 88	Parameters for the Transport Control message

Table 3.12: Unsegmented Control message format

The SEG field shall be set to 0.

The Opcode field shall be set to either 0x00 (for a Segment Acknowledgment message) or the appropriate opcode (see Table 3.39).

The Parameters field is set according to the requirements of the opcode.

3.5.2.3.1 Segment Acknowledgment message

The Segment Acknowledgment message is used by the lower transport layer to acknowledge segments received by a peer lower transport layer. The Segment Acknowledgment message is illustrated in Figure 3.12 and defined in Table 3.13.

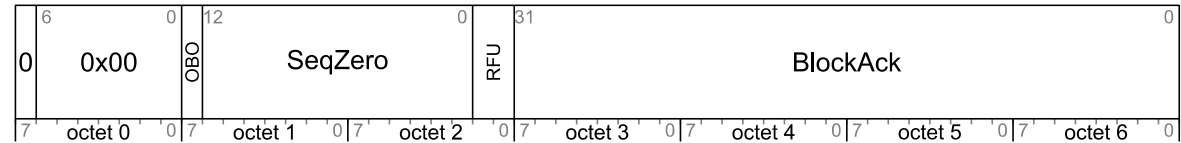


Figure 3.12: Segment Acknowledgment message

Field	Size (bits)	Notes
SEG	1	0 = Unsegmented Message
Opcode	7	0x00 = Segment Acknowledgment Message
OBO	1	Friend on behalf of a Low Power node
SeqZero	13	SeqZero of the Upper Transport PDU
RFU	2	Reserved for Future Use
BlockAck	32	Block acknowledgment for segments

Table 3.13: Segment Acknowledgment message format

The SEG field shall be set to 0.

The Opcode field of the Transport Control message shall be set to 0x00.

The OBO field shall be set to 0 by a node that is directly addressed by the received message and shall be set to 1 by a Friend node that is acknowledging this message on behalf of a Low Power node.

The SeqZero field shall be set to the SeqZero of the upper transport layer message being acknowledged.

The BlockAck field shall be set to indicate the segments received. The least significant bit, bit 0, shall represent segment 0; and the most significant bit, bit 31, shall represent segment 31. If bit *n* is set to 1, then segment *n* is being acknowledged. If bit *n* is set to 0, then segment *n* is not being acknowledged. Any bits for segments larger than SegN shall be set to 0 and ignored upon receipt.

If the received segments were sent with TTL set to 0, it is recommended that the corresponding Segment Acknowledgment message is sent with TTL set to 0.

3.5.2.4 Segmented Control message

The Segmented Control message is used to transport part of a Transport Control message when the Transport Control message will not fit into a single Network PDU. Figure 3.13 shows an illustration of a Segmented Control message, and Table 3.14 shows the fields for this message.

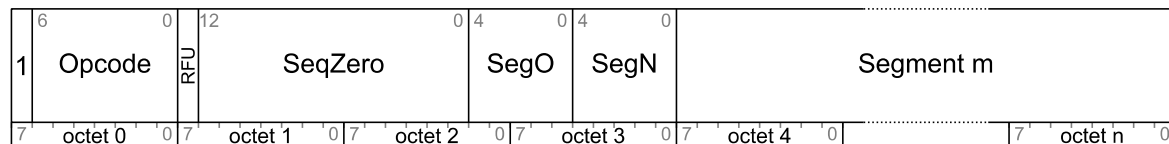


Figure 3.13: Segmented Control message

Field	Size (bits)	Notes
SEG	1	1 = Segmented Message
Opcode	7	0x00 = Reserved 0x01 to 0x7F = Opcode of the Transport Control message
RFU	1	Reserved for Future Use
SeqZero	13	Least significant bits of SeqAuth
SegO	5	Segment Offset number
SegN	5	Last Segment number
Segment m	8 to 64	Segment m of the Upper Transport Control PDU

Table 3.14: Segmented Control message format

The SEG field shall be set to 1.

The Opcode field shall be set by the upper transport layer to indicate the format of the Parameters field. The value 0x00 is Reserved and shall not be transmitted and ignored upon receipt.

The SeqZero field shall be set by the upper transport layer.

The SegO field shall be set to the segment number (zero-based) of the Upper Transport PDU contained within this message.

The SegN field shall be set to the last segment number (zero-based) of this Upper Transport PDU.

The Segment m field shall be set to the subset of octets from the Upper Transport Control PDU. Segment m shall be octets $8*m$ to $8*m+7$, except for the last segment where it is $8*m$ to the end of the message.

Every Segmented Control message for the same Upper Transport Control PDU shall have the same values for Opcode, SeqZero, and SegN.

3.5.3 Segmentation and reassembly

To transmit Upper Transport PDUs larger than 15 octets, the lower transport layer segments and reassembles Upper Transport PDUs. These segments are delivered to the peer lower transport layer using a block acknowledgment scheme to minimize the number of messages that need to be transmitted by the lower transport layer.

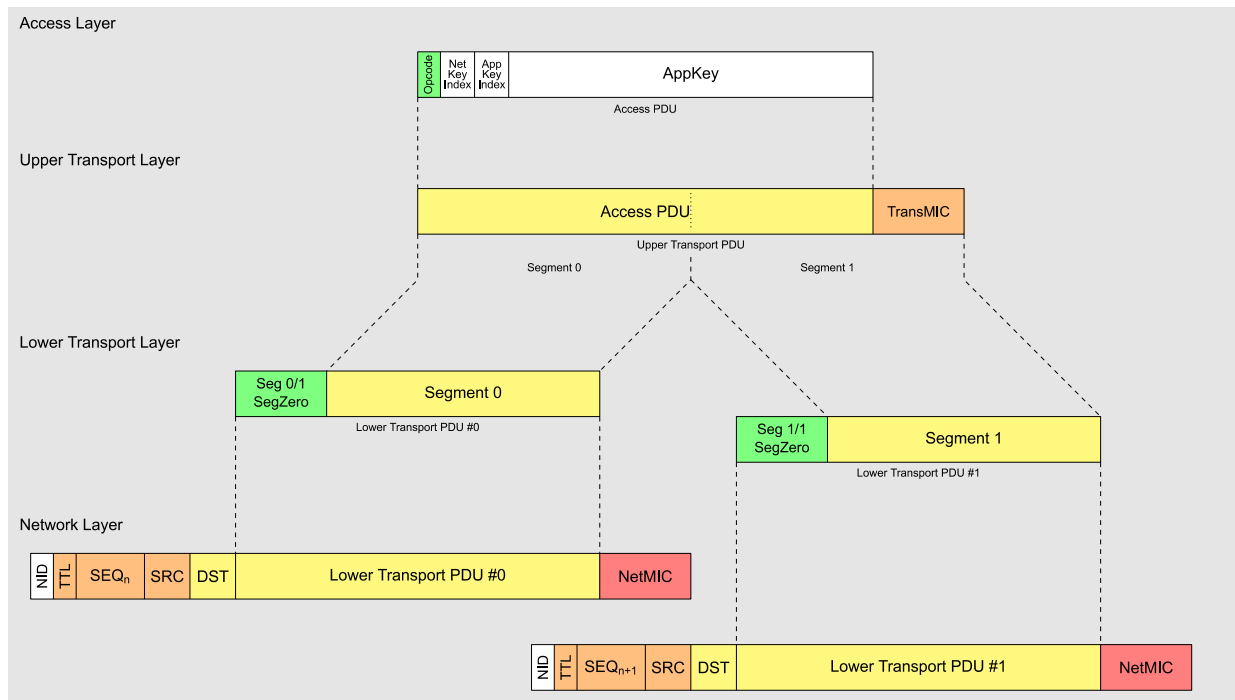


Figure 3.14: Example of segmentation and reassembly for a two-segment PDU

Figure 3.14 illustrates an Upper Transport Access PDU being sent that has a single octet opcode, 3 octets for the NetKeyIndexAndAppKeyIndex field, and 16 octets for the AppKey. This means that when encrypted and authenticated with an application key, the Upper Transport PDU is 24 octets. This is segmented by the lower transport layer into two segments, Segment 0 and Segment 1. Each segment has a header that identifies the segment number and is then passed to the network layer, where the complete Network PDU is computed. The network layer then encrypts the Network PDU using the sequence number for that Network PDU and then obfuscates those messages so that only the NID (and IV Index) octet is visible in clear text. Therefore, the single access message can be delivered securely using two Network PDUs.

The process of segmentation for Upper Transport Access PDUs and Upper Transport Control PDUs is identical, and the description below considers these two PDU types to be identical except where explicitly stated.

Note: The segment sizes are different for Upper Transport Access PDUs and Upper Transport Control PDUs.

3.5.3.1 Segmentation

The lower transport layer segments an Upper Transport PDU into one or more Lower Transport PDUs. The lower transport layer shall only transmit Segmented Access messages or Segmented Control messages for a single Upper Transport PDU to the same destination at a time. The lower transport layer should only transmit segmented messages for another Upper Transport PDU for the same destination once all segments of the last Upper Transport PDU that can be acknowledged have been acknowledged or the message has been canceled.

If the Upper Transport PDU can fit into a single Lower Transport PDU using an Unsegmented Message format, then the lower transport layer should use an unsegmented message to transmit this Upper Transport PDU. If the Upper Transport PDU can fit into a single Lower Transport PDU using a Segmented Message format, then the lower transport layer can use a single segmented message to transmit this Upper Transport PDU. Otherwise, two or more segmented messages shall be used.

Segmented messages are acknowledged at the lower transport layer, but unsegmented messages are not. A single-segment segmented message should be used when delivery of an Upper Transport PDU can be more efficiently transmitted using a segmented message than an unsegmented message.

For example, if a message is sent to acknowledge at the access layer that a multi-segment message has been received and acted upon, and this message is lost, then the complete multi-segment message must be sent again. In contrast, if the application acknowledgment message is sent in a single Segmented Access message, then the application acknowledgment message will be delivered at the lower transport layer, possibly using multiple transmissions of the segment, and thus removing the need to retransmit the multi-segment message again.

Each segment of the Upper Transport Access PDU shall be 12 octets long with the exception of the last segment, which may be shorter.

Each segment of the Upper Transport Control PDU shall be 8 octets long with the exception of the last segment, which may be shorter.

For example, when using a 32-bit TransMIC, if the Upper Transport Access PDU is 42 octets long, then the first 12 octets, octets 0 to 11, are in segment 0; the second set of 12 octets, octets 12 to 23, are in segment 1; the third set of 12 octets, octets 24 to 35, are in segment 2; and the remaining 6 octets, octets 36 to 41, are in segment 3.

For example, if the Upper Transport Control PDU is 42 octets long, then the first 8 octets, octets 0 to 7, are in segment 0; the second set of 8 octets, octets 8 to 15, are in segment 1; the third set of 8 octets, octets 16 to 23, are in segment 2; the fourth set of 8 octets, octets 24 to 31, are in segment 3; the fifth set of 8 octets, octets 32 to 39, are in segment 4; and the remaining 2 octets, octets 40 to 41, are in segment 5.

Each segment of an Upper Transport Access PDU is identified using the SegO field. The segments are linked together using the SeqAuth value used to encrypt and authenticate the Upper Transport Access PDU. Each Lower Transport PDU for an Upper Transport Access PDU shall have the same IV Index as the SeqAuth value used to encrypt and authenticate the Upper Transport Access PDU.

Each segment of an Upper Transport Control PDU is identified using the SegO field. The segments are linked together using the SeqAuth value used to transmit the first segment of the Upper Transport Control PDU. Each Lower Transport PDU for an Upper Transport Control PDU shall have the same IV Index as the SeqAuth value used to identify the Upper Transport Control PDU.

The SeqAuth is composed of the IV Index and the sequence number (SEQ) of the first segment and is therefore a 56-bit value, where the IV Index is the most significant octets and the sequence number is the least significant octets. Only the least significant 13 bits of the value (known as SeqZero) is included in the Segmented message and Segment Acknowledgment message. Upon reassembling a complete Segmented Access message, the SeqAuth value can be derived from the IV Index, SeqZero, and SEQ in

any of the segments, by determining the largest SeqAuth value for which SeqZero is between SEQ - 8191 and SEQ inclusive and using the same IV Index. For example, if the received SEQ of a message was 0x647262, the IV Index was 0x58437AF2, and the received SeqZero value was 0x1849, then the SeqAuth value is 0x58437AF2645849. If the received SEQ of a message was 0x647262 and the received SeqZero value was 0x1263, then the SeqAuth value is 0x58437AF2645263.

Because of the limited size of SeqZero, it is not possible to send a segmented message once the SEQ is 8192 higher than SeqAuth. If a segmented message has not been acknowledged by the time that SEQ is 8192 higher than SeqAuth, then the delivery of the Upper Transport PDU shall be canceled.

Each segment of the message includes both its segment offset number and the last segment number.

For example, in the above 42-octet Upper Transport Control PDU, the segments are numbered 0, 1, 2, 3, 4, and 5, and the last segment number is 5. Both the segment number (SegO) and last segment number (SegN) are included in messages to allow a receiver to always determine the size of the Upper Transport PDU (to the nearest 8 octets) after receiving any segment of the message.

3.5.3.2 Reassembly

Reassembly is performed in the receiving device. When the Low Power node feature is in use, acknowledgment of messages is performed by a Friend node and the Low Power node will not send Segment Acknowledgment messages.

Upon receiving a Segmented message, the SeqAuth shall be checked to determine if the Upper Transport PDU is being received or has previously been received. If the Segmented message has not been received yet, then the receiving device shall allocate sufficient memory, as determined by the last segment number (SegN), to store the segments of the Upper Transport PDU as they are received and keep track of the segments it has received, and it will then consider that this message is being received.

If the Low Power node feature is not in use, and if the message is destined to a unicast address, and if the node cannot receive this Upper Transport PDU at this time, for example because the node is busy or out of resources sufficient to reassemble this message, then the node shall signal to the source node that it cannot receive this Upper Transport PDU by setting the BlockAck value to 0x00000000.

If the Segmented message is in the process of being received, then the segment number (SegO) shall be used to determine where the Upper Transport PDU octets in this Segmented message shall be placed in the previously allocated memory for the message. The receiver shall update the BlockAck value to record the successful delivery of the segment.

Once all the segments of the Upper Transport PDU for a given SeqZero have been received, the upper transport layer shall check the Upper Transport PDU (see Section 3.6.4.2).

3.5.3.3 Segmentation behavior

Once an Upper Transport PDU has been segmented, the lower transport layer will transmit the initial Lower Transport PDUs of each segment of that message. If the message is destined to a unicast address, then the lower transport layer will expect a Segment Acknowledgment message from that node, or from a Friend node on behalf of that node. If the message is addressed to a virtual or group address, then Segment Acknowledgment messages will not be sent by those devices.

If the Lower Transport PDUs of the segmented Upper Transport PDU are being sent to a group address or a virtual address, then the lower transport layer shall send all Lower Transport PDUs of the segmented Upper Transport PDU. It is recommended to send all Lower Transport PDUs multiple times, introducing small random delays between repetitions.

Note: The Upper Transport PDU sent to a group or virtual address is not acknowledged by recipients, thus the message delivery status is unknown and should be considered to be unacknowledged. The behavior recommended above is designed to significantly increase the probability of the successful delivery of the segmented Upper Transport PDU.

The following requirements apply when Lower Transport PDUs are being sent to a unicast address.

When Lower Transport PDUs are sent, a segment transmission timer shall be started within which time a Segment Acknowledgment message is expected to be received. This timer shall be set to a minimum of $200 + 50 * \text{TTL}$ milliseconds.

If a Segment Acknowledgment message OBO field is set to 0, and the DST field is set to the unicast address of this element, and the SeqZero field is set to SeqZero of the segmented message, and the SRC field is set to the destination of the segmented message, the Segment Acknowledgment message is a valid acknowledgment for the segmented message.

If a Segment Acknowledgment message OBO field is set to 1, and the DST field is set to the unicast address of this element, and the SeqZero field is set to SeqZero of the segmented message, the Segment Acknowledgment message is a valid acknowledgment for the segmented message. For a given SeqAuth, only the Segment Acknowledgment messages from the first SRC address received should be considered valid.

Note: The reception of a Segment Acknowledgment message with the OBO field set to 1 does not mean that the segmented message has been delivered to the final destination, only that it has been delivered to the friend of that Low Power node. The message is stored in the Friend Queue, but the message can be discarded if other messages are received for that Low Power node or the Friendship is terminated.

If a Segment Acknowledgment message is received that is a valid acknowledgment for the segmented message, then the lower transport layer shall reset the segment transmission timer and retransmit all unacknowledged Lower Transport PDUs. If a Segment Acknowledgment message is received that acknowledges all Lower Transport PDUs for the Upper Transport PDU, then the Upper Transport PDU is complete. If a Segment Acknowledgment message with the BlockAck field set to 0x00000000 is received, then the Upper Transport PDU shall be immediately cancelled and the higher layers shall be notified that the Upper Transport PDU has been cancelled.

If the segment transmission timer expires and no valid acknowledgment for the segmented message is received, then the lower transport layer shall retransmit all unacknowledged Lower Transport PDUs.

Note: When retransmitting each Lower Transport PDU, the segment transmission timer is reset and started again.

Each Lower Transport PDU for an Upper Transport PDU shall be transmitted at least two times unless acknowledged earlier. If the lower transport layer stops retransmitting Lower Transport PDUs before all Lower Transport PDUs have been acknowledged, then the Upper Transport PDU is cancelled.



3.5.3.4 Reassembly behavior

This section only applies when the Low Power feature is not in use.

A lower transport layer has a sequence authentication value, a block acknowledgment value and an incomplete timer for each incomplete segmented message from a unique source address. An incomplete segmented message is a multi-segment message which is missing some of its segments, and whose incomplete timer has not expired. The incomplete timer defines the maximum amount of time the lower transport layer waits between unique segments of the same transaction.

A lower transport layer that receives a segment of a multi-segment message for a SeqAuth value greater than the sequence authentication value shall start an incomplete timer for that incomplete segmented message. The incomplete timer shall be set to a minimum of 10 seconds.

If the lower transport layer receives a segment for a message with a SeqAuth value less than the sequence authentication value, then it shall ignore that segment. If the lower transport layer receives a segment for a new message, then it shall save the SeqAuth value from that segment as the new sequence authentication value.

Note: The sequence authentication value logically includes the IV Index, so if a Lower Transport PDU is received using a previous IV Index, then this would be a SeqAuth value that is less than the sequence authentication value.

If a lower transport layer receives a segment of a multi-segment message but cannot accept this multi-segment message at this time because it is currently busy or out of resources to accept this message, and if the message is destined to a unicast address, the lower transport layer shall respond with a Segment Acknowledgment message with the BlockAck field set to 0x00000000.

A lower transport layer that receives a segment of a multi-segment message for a SeqAuth value greater than the sequence authentication value where the destination is a unicast address shall start an acknowledgment timer, which defines the amount of time after which the lower transport layer sends a Segment Acknowledgment message. The acknowledgment timer shall be set to a minimum of $150 + 50 * \text{TTL}$ milliseconds.

If the lower transport layer receives another segment for the sequence authentication value while the acknowledgment timer is inactive, it shall restart the acknowledgment timer.

Note: If the lower transport layer receives any segment for the sequence authentication value while the acknowledgment timer is active, then the acknowledgment timer is not restarted.

If the lower transport layer receives any segment for the sequence authentication while the incomplete timer is active, the incomplete timer shall be restarted.

The lower transport layer shall mark each segment received into a block acknowledgment value that can be later transmitted back to the source node.

When all segments of a Segmented message have been received, the lower transport layer shall send a Segment Acknowledgment message with the BlockAck field set to the block acknowledgment value for the sequence authentication value. It shall cancel the incomplete timer and the acknowledgment timer, and it shall send the reassembled message to the upper transport layer. If the segments were Segmented Access messages, then the reassembled message shall be processed as defined in Section 3.6.4.2. If



the segments were Segmented Control messages, then the reassembled message shall be processed as defined in Section 3.6.5. The lower transport layer should discard the sequence authentication value and block authentication value stored for the sender's source address after a timer of a minimum of 10 seconds has expired.

When the acknowledgment timer expires, the lower transport layer shall send a Segment Acknowledgment message with the BlockAck field set to the block acknowledgment value for the sequence authentication value.

When the incomplete timer expires, the lower transport layer shall consider that the message being received has failed and cancel the acknowledgment timer. Any segment of a canceled message whose sequence authentication value is stored by the lower transport layer shall be ignored. The lower transport should discard the sequence authentication value and block authentication value stored for that source address after a timer of a minimum of 10 seconds has expired.

If the lower transport layer receives another segment for the sequence authentication value, and the message has already been fully received (and no segment with a new sequence authentication value has been received), then it shall send a Segment Acknowledgment message immediately with the BlockAck field set to the block acknowledgment value for that SeqAuth.

If the device is acting as a Friend node for a Low Power node, then it shall reassemble Segmented messages destined for the Low Power node and act as described, except that it shall set the OBO field to 1 in the Segment Acknowledgment message. Otherwise, the OBO field shall be set to 0.

Note: A lower transport layer that receives a Segmented message that is addressed to a group or virtual address does not start the acknowledgment timer and does not send Segment Acknowledgment messages.

3.5.3.5 Low Power feature reassembly behavior

This section only applies when the Low Power feature is in use.

A lower transport layer has a sequence authentication value and a block acknowledgment value for that SeqAuth for each source device.

If the lower transport layer receives a segment for a message with a SeqAuth value less than the sequence authentication value, then it shall ignore that segment. If the lower transport layer receives a segment for a new message, then it shall save the SeqAuth value from that segment as the new sequence authentication value.

If the friendship is terminated (see Section 3.6.6.4.2), then any previously partially received multi-segment message shall be cancelled.

Note: The sequence authentication value logically includes the IV Index, so if a Lower Transport PDU is received using a previous IV Index, then this would be a SeqAuth value that is less than the sequence authentication value.

A lower transport layer that receives a segment of a multi-segment message for a SeqAuth value greater than the sequence authentication value shall start reassembling the new message, and cancel any previously partially received message.

The lower transport layer shall mark each segment received into a block acknowledgment value.

When all segments of a Segmented message have been received, the lower transport layer shall send the reassembled message to the upper transport layer. If the segments were Segmented Access messages, then the reassembled message shall be processed as defined in Section 3.6.4.2. If the segments were Segmented Control messages, then the reassembled message shall be processed as defined in Section 3.6.5.

3.5.4 Lower transport layer behavior

3.5.4.1 Transmitting a Lower Transport PDU

The Lower Transport PDU shall be delivered to the network layer.

3.5.4.2 Receiving a Lower Transport PDU

If the Lower Transport PDU is a Segmented message or a Segment Acknowledgment message, then it shall be processed as defined in Section 3.5.3.4.

If the Lower Transport PDU is an Unsegmented message type, then it shall be processed as defined in Section 3.6.4.2.

If the Lower Transport PDU is a Transport Control PDU, then it shall be processed according to the value of the Opcode field as defined in 3.6.5.

3.5.5 Friend Queue

The Friend node shall have a Friend Queue for each friend Low Power node. The Friend Queue stores Lower Transport PDUs for a Low Power node. No field of the Lower Transport PDU shall be changed due to the message being in the Friend Queue. The CTL, TTL, SEQ, SRC, and DST fields shall be stored with the associated Lower Transport PDU.

When a Friend node receives a message that is destined for a friend Low Power node (i.e., the destination of the message is a unicast address of an element of the Low Power node or in the Friend Subscription List) and the TTL field has a value of 2 or greater, then the TTL field value shall be decremented by 1, and the message shall be stored into the Friend Queue.

If the message is a Segmented Access message or a Segmented Control message, then the message shall only be stored into the Friend Queue after the complete Upper Transport PDU has been successfully reassembled and the Friend node has acknowledged the reception of all segments.

If the Friend Queue is full and a new message needs to be stored that is not a Friend Update message, the oldest entries other than a Friend Update message shall be discarded to make room for the new message.

Note: An implementation may have to discard multiple messages to fit the new message into the Friend Queue.

If the message that is being stored is a Segment Acknowledgment message and the Friend Queue contains another Segment Acknowledgment message that has the same source and destination

addresses, and the same SeqAuth value, but a lower IV Index or sequence number, then the older Segment Acknowledgment message shall be discarded.

When a Friend node becomes aware of a security update, for example by receiving a valid Secure Network beacon or by having the Key Refresh Phase state changed, it shall add a Friend Update message into the Friend Queue.

When the Low Power node requests a message from the Friend Queue, the oldest entry shall be sent. Once that message has been acknowledged by the Low Power node, that entry shall be discarded.

If the Friend node is polled for a message from a Low Power node using a Friend Poll, and the Friend Queue for that node is empty, then the Friend node shall generate a new Friend Update message and add that message to the Friend Queue before sending the response, so that this Friend Update message can be sent in response to the Friend Poll message.

3.6 Upper transport layer

The upper transport layer takes an access payload from the access layer or an internally generated upper transport layer Control message and transmits those messages to a peer upper transport layer.

For messages from the access layer, encryption and authentication of the message is performed using an application key. This allows the receiving upper transport layer to authenticate received messages.

Transport Control messages that are internally generated by the upper transport layer are only encrypted and authenticated at the network layer.

3.6.1 Endianness

All multiple-octet numeric values in this layer shall be sent in “big endian”, as described in Section 3.1.1.1.

3.6.2 Upper Transport Access PDU

When the CTL field in the Network PDU is 0, the Upper Transport Access PDU contains an access payload and is known as the Upper Transport Access PDU.

The access payload is encrypted using an application key or device key and the encrypted access payload and associated message integrity check value are combined into an Upper Transport Access PDU. The Upper Transport Access PDU fields are shown in Table 3.15 and illustrated in Figure 3.15.

Field Name	Octets	Notes
Encrypted Access Payload	1 to 380	The encrypted access payload
TransMIC	4 or 8	The message integrity check value for the access payload

Table 3.15: Upper Transport Access PDU fields

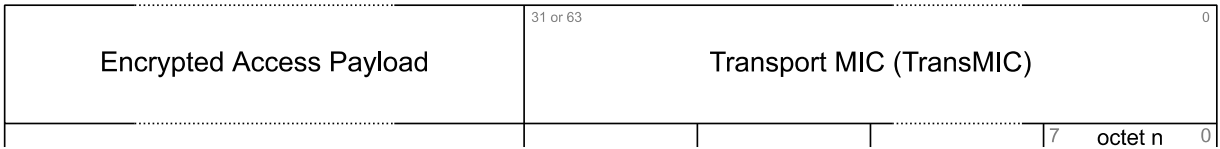


Figure 3.15: Upper Transport Access PDU format

3.6.2.1 Encrypted access payload

The access payload is supplied by the access layer. If the TransMIC is 32 bits, the access payload can be from a single octet to 380 octets in length. If the TransMIC is 64 bits, the access payload can be from a single octet to 376 octets in length. At the upper transport layer, this field is opaque and no information within this field may be used.

3.6.2.2 TransMIC

The Message Integrity Check for Transport (TransMIC) is a 32-bit or 64-bit field that authenticates that the access payload has not been changed. For a segmented message, where SEG is set to 1, the size of the TransMIC is determined by the value of the SZMIC field in the Lower Transport PDU. For unsegmented messages, the size of the TransMIC is 32 bits for data messages.

Note: Control messages do not have a TransMIC.

3.6.3 Upper Transport Control PDU

When the CTL bit is 1, the Upper Transport PDU contains a transport control message. A transport control message has a 7-bit opcode that determines the format of the parameters. This Opcode field is not included in the parameters field, but is included in the Lower Transport PDU Unsegmented Control message or in each segment of a Segmented Control Message.

The Upper Transport Control PDU is not authenticated at the upper transport layer and instead relies upon the authentication performed by the network layer. All Upper Transport Control PDUs use a 64-bit NetMIC.

The lower transport layer may segment messages into smaller PDUs for delivery over the network layer. It is therefore recommended to keep Transport Control PDU payload size as reflected in [Table 3.16](#), where the values represent the maximum useful parameter field sizes depending on the number of packets.

Number of Packets	Transport Control PDU Payload Size
1	11 (Unsegmented)
1	8 (Segmented)
2	16
3	24
n	n*8
32	256

Table 3.16: Maximum Useful Transport Control PDU payload sizes



The maximum size of an Upper Transport Control PDU is 256 octets.

3.6.4 Upper transport layer behavior

3.6.4.1 Transmitting an access payload

All access messages are sent in the context of an application key or a device key. The access payload shall be encrypted using this application key or device key, and the TransMIC shall be set to the message integrity check value, as defined in Section 3.8.6. The Upper Transport PDU shall then be processed as defined in Section 3.5.4.1.

A sequence number (SEQ) shall be allocated to this message. In the context of a message segmented in the lower transport layer, this SEQ corresponds to the 24 lowest bits of SeqAuth, the sequence number used for authenticating and decrypting the access message by the receiver, as defined in chapter 3.5.3.1.

The AKF and AID fields of the Lower Transport PDU shall be set according to the application key or device key used to encrypt and authenticate the Upper Transport PDU. If an application key is used, then the AKF field shall be set to 1 and the AID field shall be set to the application key identifier (AID). If the device key is used, then the AKF field shall be set to 0 and the AID field shall be set to 0b000000.

The upper transport layer shall not transmit a new segmented Upper Transport PDU to a given destination until the previous Upper Transport PDU to that destination has been either completed or cancelled.

3.6.4.2 Receiving an Upper Transport PDU

Upon receiving an Upper Transport Access PDU, the access payload shall be decrypted and the TransMIC shall be authenticated against all known application keys or the device key for which the AKF and AID fields match. If the Upper Transport Access PDU authenticates and it has been checked for replay attacks (see Section 3.8.8) then it is delivered to the access layer with the contextual information of this message such as the source address, destination addresses, and the keys used for decryption and authentication.

Upon receiving an Upper Transport Control PDU, the destination address of the PDU shall be checked against the unicast address of the elements of this node and if it matches then the message shall be processed (see Section 3.6.6).

If this node supports the Friend feature and this feature is enabled, the node has a friendship with a Low Power node, and the destination address of this message is an address that is currently in the Friend Subscription List for this Low Power node, then the message shall be stored in the appropriate Friend Queue.

3.6.5 Transport Control messages

The Transport Control messages can be transmitted using either a single Unsegmented Control message or sequence of Segmented Control messages. Each of these messages has a 7-bit opcode field that determines the format of the parameters field. Each Transport Control Message shall be sent in the smallest number of Lower Transport PDUs possible.

Opcode 0x00 is terminated at the lower transport layer and used in the Segmentation and Reassembly of messages and shall not be sent by the upper transport layer. All other control messages are terminated at the upper transport layer.

See [Table 3.39](#) for a summary of Transport Control Message opcodes.

3.6.5.1 Friend Poll

The Friend Poll message is sent by a Low Power node to ask the Friend node to send a message that it has stored for the Low Power node.

The Friend Poll message parameters are defined in [Table 3.17](#).

Field	Size (bits)	Notes
Padding	7	0b0000000. All other values are Prohibited.
FSN	1	Friend Sequence Number, used to acknowledge receipt of previous messages from the Friend node to the Low Power node

Table 3.17: Friend Poll message parameters

The Opcode field of the Transport Control message shall be set to 0x01.

The FSN field shall be set to 0 or 1, as defined in [Section 3.6.6.4.2](#).

This message shall set the TTL field of the Network PDU to 0.

This message shall be sent using the friendship security credentials.

3.6.5.2 Friend Update

The Friend Update message is sent by a Friend node to a Low Power node to inform the Low Power node that the security parameters (see [Section 3.6.6.1](#)) for the network have changed or are changing, or that the Friend Queue is empty.

The Friend Update message parameters are defined in [Table 3.18](#).

Field	Size (octets)	Notes
Flags	1	Contains the IV Update Flag and the Key Refresh Flag
IV Index	4	The current IV Index value known by the Friend node
MD	1	Indicates if the Friend Queue is empty or not.

Table 3.18: Friend Update message parameters

The Opcode field of the Transport Control message shall be set to 0x02.

The Flags field is an 8-bit field as defined in [Table 3.19](#):



Bit	Definition
0	Key Refresh Flag 0: Not-In-Phase2 1: In-Phase2
1	IV Update Flag 0: Normal operation 1: IV Update active
2–7	Reserved for Future Use

Table 3.19: Flags field format

The Key Refresh Flag indicates whether the Key Refresh procedure is in progress (see Section 3.10.4).

The IV Update Flag indicates whether the IV Update procedure is in progress (see Section 3.10.5).

The IV Index field contains the current IV Index.

The MD field is set to indicate if the Friend Queue is empty or not, as defined in Table 3.20.

Value	Description
0	Friend Queue is empty
1	Friend Queue is not empty
2–255	Prohibited

Table 3.20: MD field format

This message shall set the TTL field of the Network PDU to 0.

This message shall be sent using the friendship security credentials.

3.6.5.3 Friend Request

The Friend Request message is sent to the all-friends group by a Low Power node to start to find a friend.

The Friend Request message parameters are defined in Table 3.21.

Field	Size (octets)	Notes
Criteria	1	The criteria that a Friend node should support in order to participate in friendship negotiation
ReceiveDelay	1	Receive delay requested by the Low Power node
PollTimeout	3	The initial value of the PollTimeout timer set by the Low Power node
PreviousAddress	2	Unicast address of the primary element of the previous friend
NumElements	1	Number of elements in the Low Power node

LPNCounter	2	Number of Friend Request messages that the Low Power node has sent
------------	---	--

Table 3.21: Friend Request message parameters

The Opcode field of the Transport Control message shall be set to 0x03.

The Criteria field format is defined in [Table 3.22](#).

Field	Size (bits)	Notes
RFU	1	Reserved for Future Use
RSSIFactor	2	The contribution of the RSSI measured by the Friend node used in Friend Offer Delay calculations
ReceiveWindowFactor	2	The contribution of the supported Receive Window used in Friend Offer Delay calculations
MinQueueSizeLog	3	The minimum number of messages that the Friend node can store in its Friend Queue

Table 3.22: Criteria field format

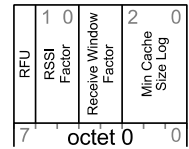


Figure 3.16: Criteria field format

The RSSIFactor field is used in the Friend Offer Delay calculation (see Section 3.6.6.3.1) and the values are defined in [Table 3.23](#).

Value	RSSI Factor
0b00	1
0b01	1.5
0b10	2
0b11	2.5

Table 3.23: RSSIFactor field values

The ReceiveWindowFactor field is used in the Friend Offer Delay calculation (see Section 3.6.6.3.1) and the values are defined in [Table 3.24](#).

Value	Receive Window Factor
0b00	1
0b01	1.5
0b10	2

0b11	2.5
------	-----

Table 3.24: *ReceiveWindowFactor* field values

The *MinQueueSizeLog* field is defined as $\log_2(N)$, where N is the minimum number of maximum size Lower Transport PDUs that the Friend node can store in its Friend Queue and has one of the values defined in [Table 3.25](#).

Value	Description
0b000	Prohibited
0b001	N = 2
0b010	N = 4
0b011	N = 8
0b100	N = 16
0b101	N = 32
0b110	N = 64
0b111	N = 128

Table 3.25: *MinQueueSizeLog* field values

The *ReceiveDelay* field shall be set within the valid range as defined in [Table 3.26](#).

Value	Description
0x00–0x09	Prohibited
0x0A–0xFF	Receive Delay in units of 1 millisecond

Table 3.26: *ReceiveDelay* field values

The *PollTimeout* field shall be set within the valid range as defined in [Table 3.27](#).

Value	Description
0x000000–0x000009	Prohibited
0x00000A–0x34BBFF	PollTimeout in units of 100 milliseconds
0x34BC00–0xFFFFFFFF	Prohibited

Table 3.27: *PollTimeout* field values

The *PreviousAddress* field shall be set to the previous Friend's unicast address or the unassigned address if no previous friendship was established.

The *NumElements* field shall be set to the number of elements on the Low Power node. The value is used by the Friend node to calculate the range of unicast addresses assigned to the Low Power node using the SRC address of this message.

The values of *NumElements* are defined in [Table 3.28](#).



Value	Description
0x00	Prohibited
0x01–0xFF	Number of elements

Table 3.28: NumElements value definitions

The LPNCounter field value is set to the number of Friend Request messages that the Low Power node has sent to date.

This message shall set the TTL field of the Network PDU to 0.

This message shall be sent using the master security credentials.

3.6.5.4 Friend Offer

The Friend Offer message is sent by a Friend node to offer a friendship.

The Friend Offer message parameters are defined in Table 3.29.

Field	Size (octets)	Notes
ReceiveWindow	1	Receive Window value supported by the Friend node
QueueSize	1	Queue Size available on the Friend node
SubscriptionListSize	1	Size of the Subscription List that can be supported by a Friend node for a Low Power node
RSSI	1	RSSI measured by the Friend node
FriendCounter	2	Number of Friend Offer messages that the Friend node has sent

Table 3.29: Friend Offer parameters

The Opcode field of the Transport Control message shall be set to 0x04.

The values of ReceiveWindow are defined in Table 3.30.

Value	Description
0x00	Prohibited
0x01–0xFF	Receive Window in units of 1 millisecond

Table 3.30: ReceiveWindow value definitions

The QueueSize field contains the number of messages that the Friend node can store for the Low Power node.

The SubscriptionListSize field contains the number of entries in the subscription list that the Friend node can support for the Low Power node.

The RSSI field contains a signed 8-bit value, and is interpreted as an indication of received signal strength measured in dBm. This is measured by the Friend node on the Friend Request. The value shall be 0x7F (127 dBm) if the signal strength indication is not available.

The FriendCounter field value is set to the number of Friend Offer messages that the Friend node has sent.

This message shall set the TTL field of the Network PDU to 0.

This message shall be sent using the master security credentials.

3.6.5.5 Friend Clear

The Friend Clear message is sent to a Friend node to inform it about the removal of a friendship.

The Friend Clear message parameters are defined in [Table 3.31](#).

Field	Size (octets)	Notes
LPNAddress	2	The unicast address of the Low Power node being removed
LPNCounter	2	Value of the LPNCounter of new relationship

Table 3.31: Friend Clear parameters

The Opcode field of the Transport Control message shall be set to 0x05.

The LPNAddress field shall be set to the unicast address of the Low Power node that is being removed.

The LPNCounter field shall be set to the LPNCounter value from the latest Friend Request used to establish the relationship.

This is a confirmed message and the sending node expects to receive a Friend Clear Confirm message in response. If the Friend node does not receive a response, the new Friend node should resend the message at doubling intervals (2, 4, 8, 16 seconds etc.) until it either receives a response or it reaches the Poll Timeout of the Low Power node.

This message shall be sent using the master security credentials.

3.6.5.6 Friend Clear Confirm

The Friend Clear Confirm message is sent by the old Friend node in response to the Friend Clear message to confirm that the friendship has been terminated. If the Friend Clear message was received with a TTL of 0, the confirmation should use TTL of 0 as well.

The Friend Clear Confirm message parameter is defined in [Table 3.32](#).

Field	Size (octets)	Notes
LPNAddress	2	The unicast address of the Low Power node being removed

LPNCounter	2	The value of the LPNCounter of corresponding Friend Clear message
------------	---	---

Table 3.32: Friend Clear Confirm parameters

The Opcode field of the Transport Control message shall be set to 0x06.

The LPNAddress field shall be set to the unicast address of the Low Power node that was removed.

The LPNCounter field shall be set to the LPNCounter value from the corresponding Friend Clear message.

The message should only be sent in response to a valid Friend Clear message received within the Poll Timeout of the previous friend relationship, but it should send a Friend Clear Confirm message for each valid Friend Clear message that it receives in that period. A Friend Clear message is considered valid if the result of the subtraction of the value of the LPNCounter field of the Friend Request message (the one that initiated the friendship) from the value of the LPNCounter field of the Friend Clear message, modulo 65536, is in the range 0 to 255 inclusive.

This message shall be sent using the master security credentials.

3.6.5.7 Friend Subscription List Add

The Friend Subscription List Add message is sent by a Low Power node to a Friend node to indicate the list of group addresses and virtual addresses for which messages are to be stored.

The Friend Subscription List Add message parameter is defined in Table 3.33.

Field	Size (octets)	Notes
TransactionNumber	1	The number for identifying a transaction
AddressList	2 * N	List of group addresses and virtual addresses where N is the number of group addresses and virtual addresses in this message

Table 3.33: Friend Subscription List Add parameters

The Opcode field of the Transport Control message shall be set to 0x07.

The TransactionNumber field is used to distinguish each individual transaction (see Section 3.6.6.4.3).

The AddressList field shall contain a list of group addresses and virtual addresses to add to the Friend Subscription List.

Note: When this message is sent as an Unsegmented Control message, the AddressList field cannot contain more than 5 addresses.

This message shall set the TTL field of the Network PDU to 0.

This message shall be sent using the friendship security credentials.



3.6.5.8 Friend Subscription List Remove

The Friend Subscription List Remove message is sent by a Low Power node to a Friend node to indicate the group addresses and virtual addresses to remove from the Friend Subscription List.

The Friend Subscription List Remove message parameters are defined in [Table 3.34](#).

Field	Size (octets)	Notes
TransactionNumber	1	The number for identifying a transaction
AddressList	2 * N	List of group addresses and virtual addresses where N is the number of group addresses and virtual addresses in this message

Table 3.34: Friend Subscription List Remove parameters

The Opcode field of the Transport Control message shall be set to 0x08.

The TransactionNumber field is used to distinguish each individual transaction (see Section 3.6.6.4.3).

The AddressList field shall contain a list of group addresses and virtual addresses to remove from the Friend Subscription List.

Note: When this message is sent as an Unsegmented Control message, the AddressList field cannot contain more than 5 addresses.

This message shall set the TTL field of the Network PDU to 0.

This message shall be sent using the friendship security credentials.

3.6.5.9 Friend Subscription List Confirm

The Friend Subscription List Confirm message is sent by a Friend node to a Low Power node to respond to a Friend Subscription List Add message or Friend Subscription List Remove message.

The Opcode field of the Transport Control Message shall be set to 0x09.

The Friend Subscription List Confirm message parameters are defined in [Table 3.35](#).

Field	Size (octets)	Notes
TransactionNumber	1	The number for identifying a transaction

Table 3.35: Friend Subscription List Confirm parameters

The TransactionNumber field is used to distinguish each individual transaction (see Section 3.6.6.4.3).

This message shall set the TTL field of the Network PDU to 0.

This message shall be sent using the friendship security credentials.

3.6.5.10 Heartbeat

The Heartbeat message is sent by a node to let other nodes determine topology of a subnet.



The Heartbeat message parameters are defined in [Table 3.36](#).

Field	Size (bits)	Notes
RFU	1	Reserved for Future Use
InitTTL	7	Initial TTL used when sending the message
Features	16	Bit field of currently active features of the node

Table 3.36: Heartbeat parameters

The Opcode field of the Transport Control message shall be set to 0x0A.

The values of InitTTL are defined in [Table 3.37](#).

Value	Description
0x00–0x7F	Initial TTL when sending a message

Table 3.37: InitTTL value definitions

The InitTTL field contains the initial TTL used when sending the message.

The Features field contains a bit field indicating the features the node currently uses, as defined in [Section 3.1](#). The format of the Features field is defined in [Table 3.38](#).

Bit	Feature	Notes
0	Relay	Relay feature in use: 0 = False, 1 = True
1	Proxy	Proxy feature in use: 0 = False, 1 = True
2	Friend	Friend feature in use: 0 = False, 1 = True
3	Low Power	Low Power feature in use: 0 = False, 1 = True
4–15	RFU	Reserved for Future Use

Table 3.38: Features field format

3.6.5.11 Summary of opcodes

[Table 3.39](#) provides a summary of opcodes used by Transport Control messages.

Value	Opcode	Notes
0x00	–	Reserved for lower transport layer
0x01	Friend Poll	Sent by a Low Power node to its Friend node to request any messages that it has stored for the Low Power node
0x02	Friend Update	Sent by a Friend node to a Low Power node to inform it about security updates



Value	Opcode	Notes
0x03	Friend Request	Sent by a Low Power node the all-friends fixed group address to start to find a friend
0x04	Friend Offer	Sent by a Friend node to a Low Power node to offer to become its friend
0x05	Friend Clear	Sent to a Friend node to inform a previous friend of a Low Power node about the removal of a friendship
0x06	Friend Clear Confirm	Sent from a previous friend to Friend node to confirm that a prior friend relationship has been removed
0x07	Friend Subscription List Add	Sent to a Friend node to add one or more addresses to the Friend Subscription List
0x08	Friend Subscription List Remove	Sent to a Friend node to remove one or more addresses from the Friend Subscription List
0x09	Friend Subscription List Confirm	Sent by a Friend node to confirm Friend Subscription List updates
0x0A	Heartbeat	Sent by a node to let other nodes determine topology of a subnet
0x0B–0x7F	RFU	Reserved for Future Use

Table 3.39: Summary of Transport Control message opcodes

3.6.6 Friendship

A Friend node can store messages for a Low Power node.

3.6.6.1 Functional overview

In order to optimize the power consumption of a Low Power node, a polling mechanism is used to minimize the Low Power node's receive window. This allows a Low Power node to receive updates from a Friend node by indicating when it is available to receive messages.

Friendship defines timing parameters that are static for the duration of a friend relationship between a Low Power node and a Friend node.

The following timing parameters are used in a friendship:

- ReceiveDelay
- ReceiveWindow
- PollTimeout

The ReceiveDelay is the time between the Low Power node sending a request and listening for a response. This delay allows the Friend node time to prepare the response.

The ReceiveWindow is the time that the Low Power node listens for a response. When the Low Power node receives a message from its Friend node, it can stop listening for additional messages.



The request can be a Friend Poll message, a Friend Subscription List Add message, or a Friend Subscription List Remove message. The response to a Friend Poll message can be a Friend Update message or a stored message. The response to a Friend Subscription List Add message or a Friend Subscription List Remove message is a Friend Subscription List Confirm message.

The timing parameters are illustrated in [Figure 3.17](#).

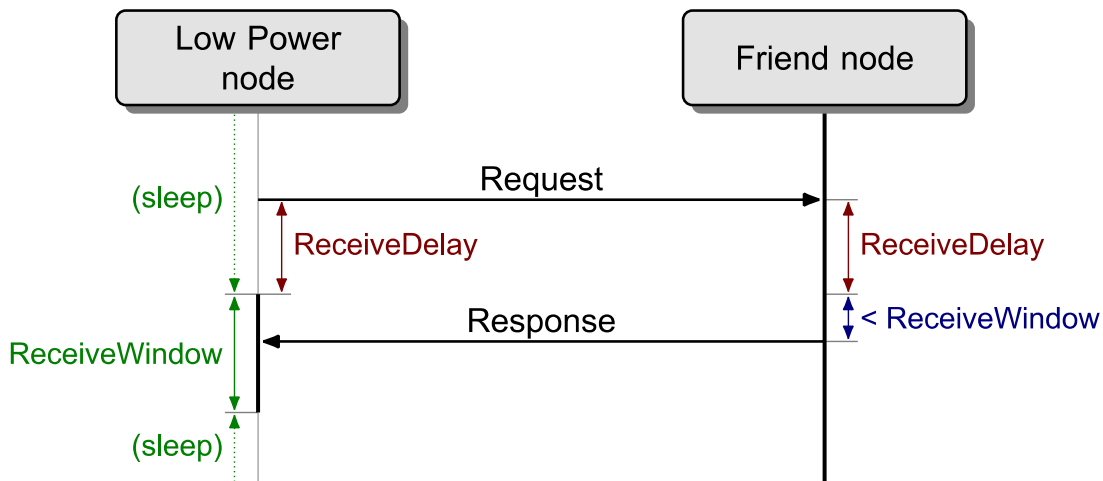


Figure 3.17: Friendship timing parameters

PollTimeout timer is used to measure time between two consecutive requests sent by the Low Power node. If no requests are received by the Friend node before the PollTimeout timer expires, then the friendship is considered terminated. This is illustrated in [Figure 3.18](#).

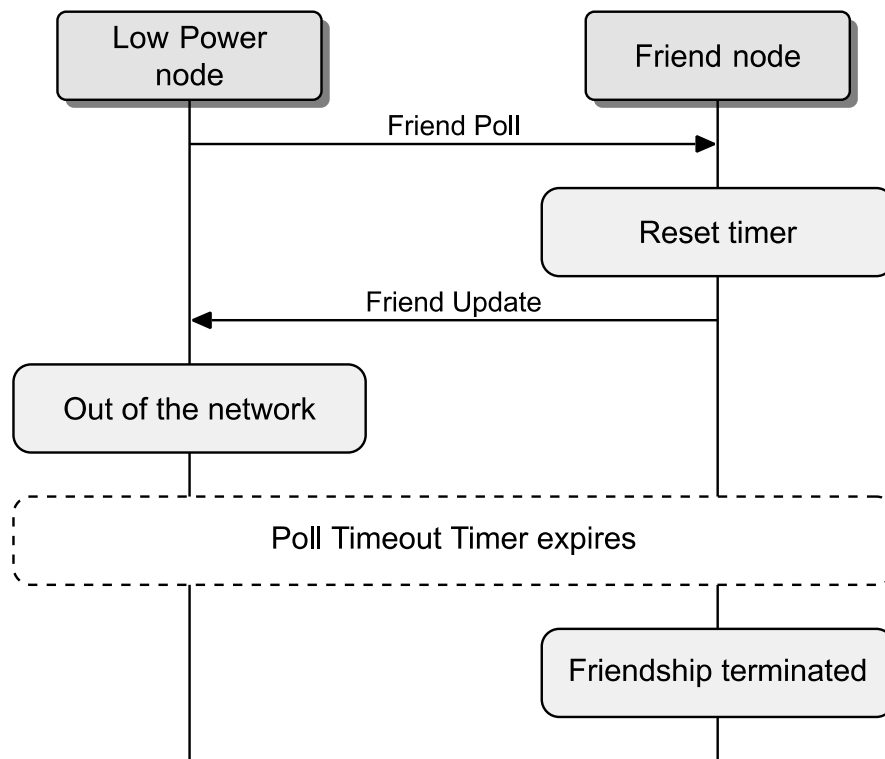


Figure 3.18: Poll Timeout timer illustration

To establish a friendship, a node that supports the Low Power feature sends a Friend Request to the all-friends address. The message is picked up by all nodes within radio range of this node that support the Friend feature.

The Friend Request message includes a number of parameters that define the requirements that this node requires any future Friend node to support. Each of the nodes that support the Friend feature and that can support the requirements of the Friend Request message responds by sending back a Friend Offer message to the requesting node. The offers also include additional information about the capabilities of each of the offering nodes. This allows the Low Power node to determine which of these offers it will accept.

The Low Power node then sends a Friend Poll message to its chosen Friend node, and the Friend node responds with a Friend Update message. At this point, the friendship is established, as illustrated in [Figure 3.19](#).

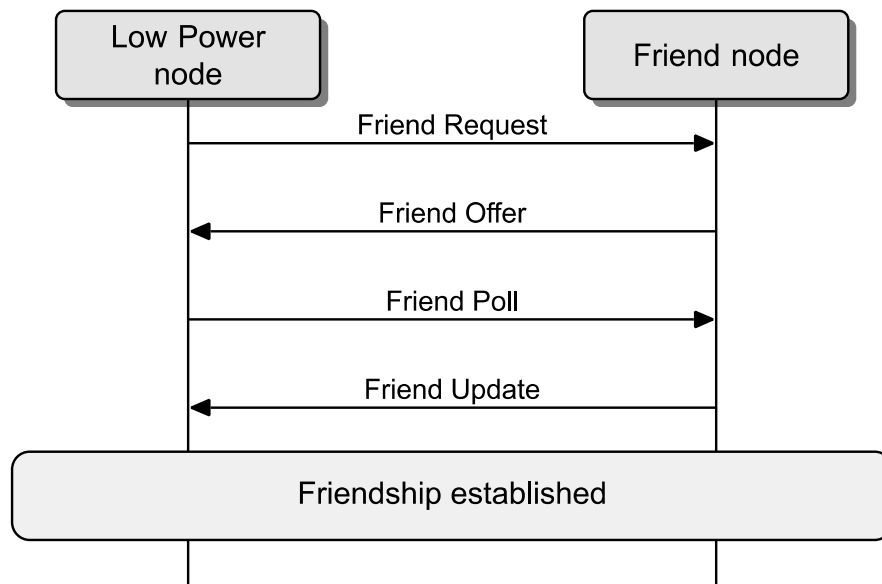


Figure 3.19: Establishment of a friendship

If the Low Power node was previously a friend of another Friend node, then the new Friend node informs the old Friend node that it is now the current friend of this Low Power node (see Section 3.6.6.3.1).

After a friendship is established, the Friend node stores a Friend Subscription List for the Low Power node, which is a collection of group and virtual addresses to which the Low Power node is subscribed. This list allows the Friend node to store the messages that the Low Power node is subscribed to.

The values of the IV Index, IV Update flag, and Key Refresh Flag for a given NetKey are known as security parameters. Whenever at least one of the values of the security parameters is changed, the new security parameters are known as security updates.

The Friend node stores all messages for the Low Power node, and also the most recent security updates for the Low Power node, in the Friend Queue. Collectively these are known as stored messages.

To obtain stored messages, the Low Power node sends Friend Poll messages and the Friend node replies with stored messages.

Messages stored in the Friend Queue are delivered to the Low Power node with acknowledgment and in order. To enable this, a Friend Sequence Number is used. This value is stored on the Low Power node and is sent in each Friend Poll message. When the Low Power node receives a message in response to a Friend Poll, and this message has been successfully authenticated using the friendship security credentials, the Low Power node shall change this Friend Sequence Number. The next time this Low Power node polls, the Friend node can send the next message. If there was no response to the Friend Poll message, then the Low Power node does not change the Friend Sequence Number and the Friend node can then determine that the last message it sent was not received and resend it.

3.6.6.2 Friendship security

When a friendship has been established between a Friend node and a Low Power node, all network messages from the Friend node to the Low Power Node are secured using the friendship security material created from the friendship security credentials (see Section 3.8.6.3.1). The friendship security credentials are exchanged during the Low Power Establishment procedure (see Section 3.6.6.4.1).

The Friend Poll, Friend Update, and Friend Subscription List Add/Remove/Confirm messages, as well as stored messages that the Friend node delivers to the Low Power node, are always encrypted using the friendship security credentials. The Friend Clear and Friend Clear Confirm messages are always encrypted using the master security credentials.

Depending on the value of the Publish Friendship Credentials Flag (see Section 4.2.2.4), the Low Power node sends a message using either the friendship security credentials or the master security credentials (see Section 3.8.6.3.1).

All other network messages are sent using the master security credentials.

Figure 3.20 illustrates messages secured using the friendship security credentials (dashed lines) and with the master security credentials (solid lines). The Low Power node starts by sending the Friend Request message using the master security credentials. A Friend node responds with a Friend Offer message, again using the master security credentials. Both the Low Power node and the Friend node must use the master security credentials as neither device is in a friendship with the other and therefore cannot use the friendship security credentials. The Low Power node accepts the offer of friendship and sends a Friend Poll to confirm this using the friendship security credentials. The Friend node will respond to this using a Friend Update message. The Low Power node can now configure the friend subscription list by using the Friend Subscription List Add message, confirmed using the Friend Subscription List Confirm message from the Friend node. Both of these messages are sent using the friendship security credentials.

Sometime later, the Friend node receives a message (InMsg) from another device that needs to be delivered to the Low Power node, so it will store this message in the Friend Queue. The Low Power node sends a Friend Poll message, secured using the friendship security credentials, to which the Friend node will reply with the stored InMsg.

The Low Power node then decides to send two messages: OutMsg1 and OutMsg2. OutMsg1 is sent secured using the friend security credentials and therefore only the Friend node will receive and relay this message. When the Friend node relays OutMsg1, the message will be retransmitted using the master security credentials. OutMsg2 is sent secured using the master security credentials and therefore the Friend node and any other Relay node within range of the Low Power node can relay the message. OutMsg2, when it is relayed, will be retransmitted using the master security credentials.



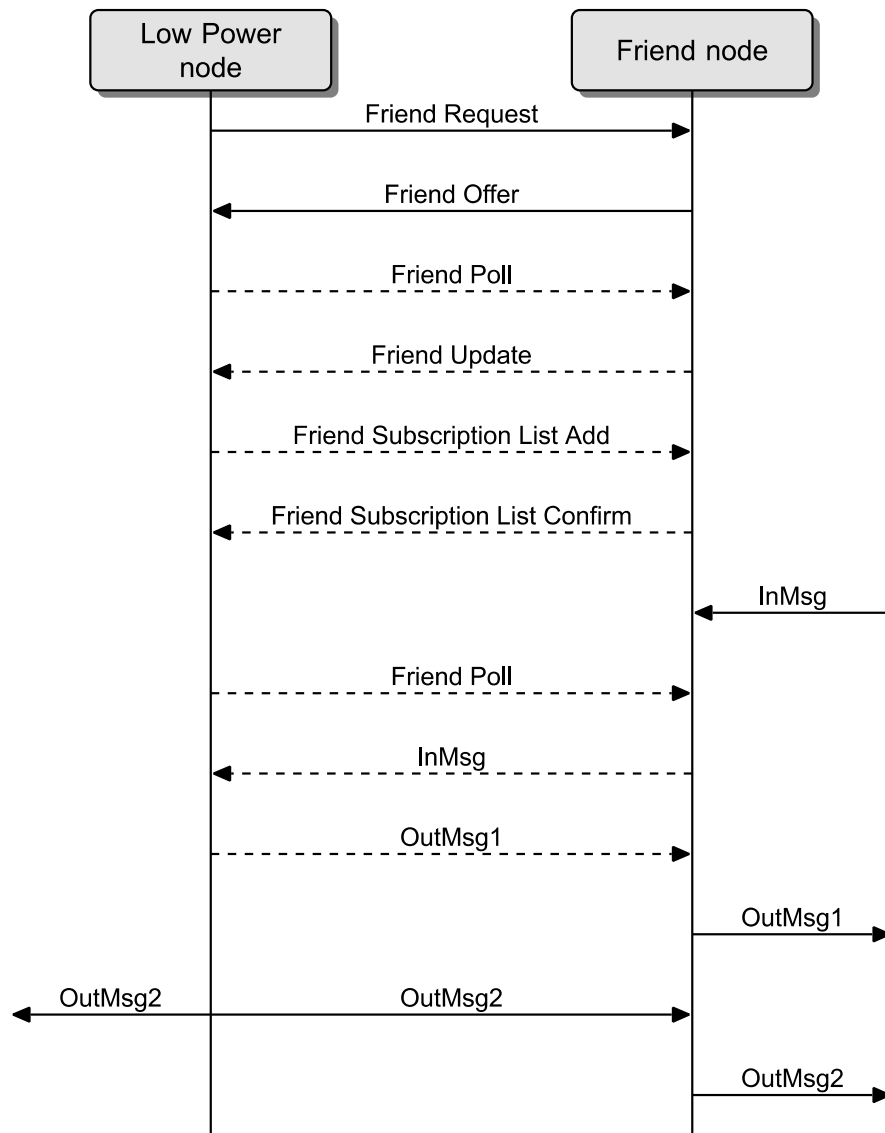


Figure 3.20: Messages secured with friendship and master security credentials

3.6.6.3 Friend feature

The Friend feature defines three mandatory operations: friend establishment, friend messaging, and friend management.

All transport control messages originated by a Friend node shall be sent as Unsegmented Control messages with the SRC field set to the unicast address of the primary element of the Friend node.

3.6.6.3.1 Friend establishment

A node that supports the Friend feature and has the feature enabled, and that receives a Friend Request message (see Section 3.6.5.3), that fulfills the minimum requirements specified by the message parameters shall respond with a Friend Offer message (see Section 3.6.5.4).

If the source address of the Friend Request message is an address of a Low Power node that is currently in a friendship with the Friend node, then the Friend node shall also consider the existing friendship with that Low Power node terminated.

The Friend Offer message shall be sent with the destination equal to the source address of the Friend Request message and the TTL value set to 0.

The node shall keep a Friend node counter (FriendCounter), which is a 2-octet value initialized to 0. This value shall be sent in the Friend Offer message and shall be used to derive the friendship security material if a friendship is established as a result of the Friend Offer message. After each Friend Offer message is sent, the FriendCounter value shall be incremented by 1. The FriendCounter may wrap.

The time between receiving the Friend Request message and sending the Friend Offer message is called the Friend Offer Delay and shall be computed based on the RSSIFactor field and the ReceiveWindowFactor field as defined in the Friend Request message on the supported ReceiveWindow and on the RSSI measured by the Friend node for the Friend Request message.

The Friend Offer Delay allows a Low Power node to receive Friend Offer messages from potential Friend nodes in order to determine how large the offered ReceiveWindow is, and how important the signal quality is. Some Low Power nodes will prefer Friend nodes with a very small ReceiveWindow and therefore set the ReceiveWindowFactor to be more important than the RSSIFactor. Other Low Power nodes will prefer Friends with a very good signal strength and therefore set the RSSIFactor to be more important than the ReceiveWindowFactor. This means that the Low Power node should receive Friend Offers from Friends quicker for those nodes that match the Low Power nodes requirements, reducing the power consumed by the Low Power node when searching for a Friend node.

A Local Delay is computed with the formula:

$$\text{Local Delay} = \text{ReceiveWindowFactor} * \text{ReceiveWindow} - \text{RSSIFactor} * \text{RSSI}$$

Where:

ReceiveWindowFactor is a number from the Friend Request message

ReceiveWindow is the value to be sent in the corresponding Friend Offer message

RSSIFactor is a number from the Friend Request message

RSSI is the received signal strength of the received Friend Request message on the Friend node

If the Local Delay value is greater than 100, then the Friend Offer Delay value in milliseconds shall be set to the Local Delay value. Otherwise, the Friend Offer Delay shall be set to 100 milliseconds.

If the node receives a Friend Poll message within 1 second after sending the Friend Offer message, the friendship is established and it shall save the FSN field value from this Friend Poll message; otherwise, the establishment has failed.

The Friend node shall respond with a Friend Update message after a minimum of ReceiveDelay milliseconds and before a maximum of the sum of ReceiveDelay and ReceiveWindow milliseconds, from the reception of the Friend Poll message from the Low Power node.

Figure 3.21 illustrates a friendship establishment where multiple nodes with the Friend feature enabled receive the same Friend Request message.

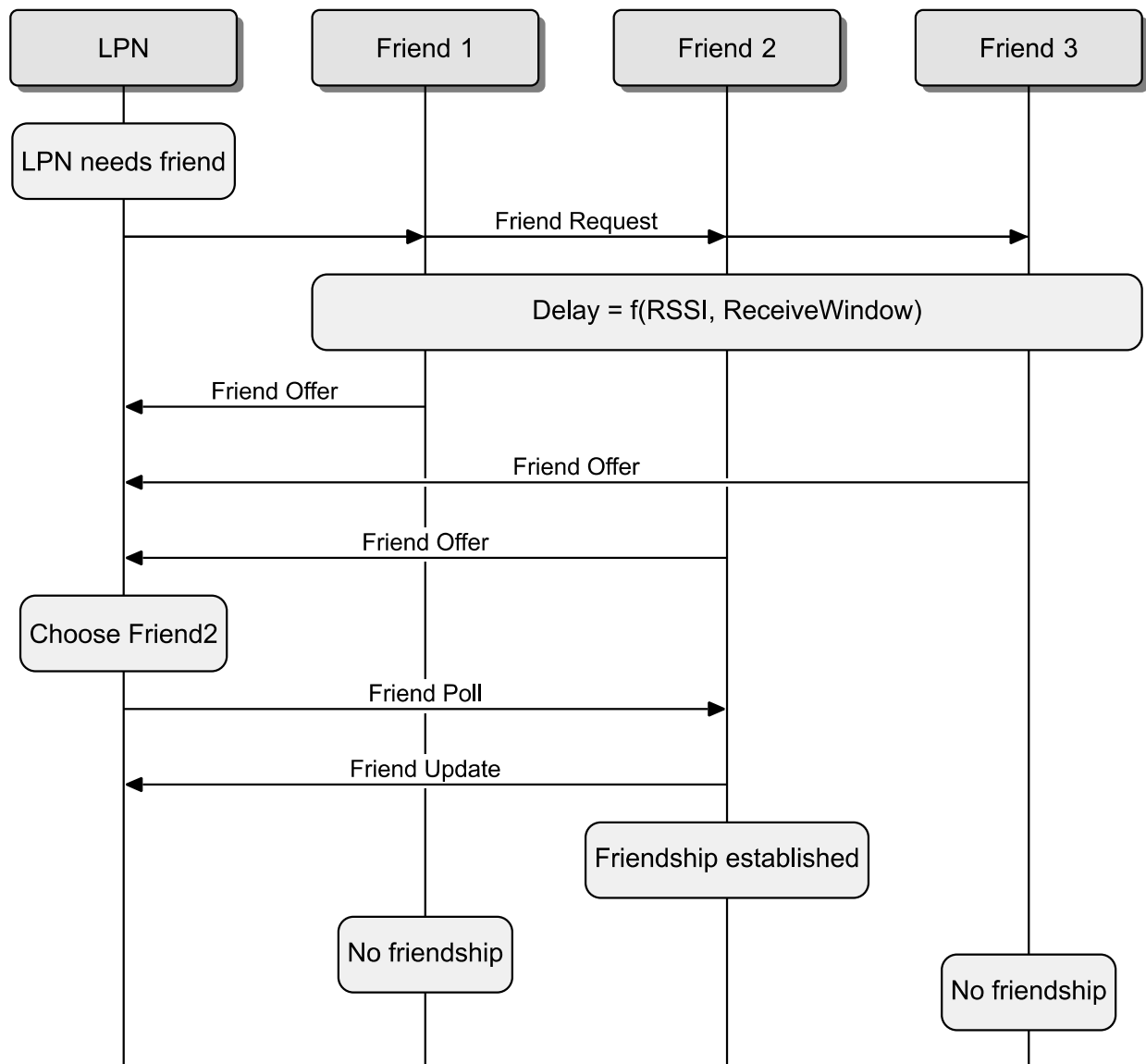


Figure 3.21: Friend establishment example

After a friendship is established, the Friend node shall initialize a Friend Subscription List to a zero-length (empty) list and start storing messages for the Low Power node in the Friend Queue.

After a friendship has been established, if the PreviousAddress field of the Friend Request message contains a valid unicast address that is not the Friend node's own unicast address, then the Friend node

shall begin sending Friend Clear messages (see Section 3.6.5.5) to that unicast address according to the procedure below:

1. The TTL shall be set to the maximum valid value.
2. The first Friend Clear message shall be sent as soon as the friendship is established; at the same time, a Friend Clear Repeat timer shall be started with the period set to 1 second, and a Friend Clear Procedure timer shall be started with the period equal to two times the Friend Poll Timeout value.
3. If a Friend Clear Confirm message (see Section 3.6.5.6) is received in response to the Friend Clear message, both timers shall be canceled and the procedure is complete.
4. If the Friend Clear Repeat timer expires, a new Friend Clear message shall be sent and the timer shall be restarted with a period that is double the previous Friend Clear Repeat timer period. For example, after the first expiration, the period shall be set to two seconds; on the next expiration, it shall be set to four seconds, and so on.
5. If the Friend Clear Procedure timer expires, then the Friend Clear Repeat timer shall be cancelled and the procedure is complete.

An example of this procedure is illustrated in [Figure 3.22](#).

Once friendship has been established the Friend node shall communicate with the Low Power node as defined in friend messaging (see Section 3.6.6.3.2), and may be managed as defined in Friend Management (see Section 3.6.6.3.3).

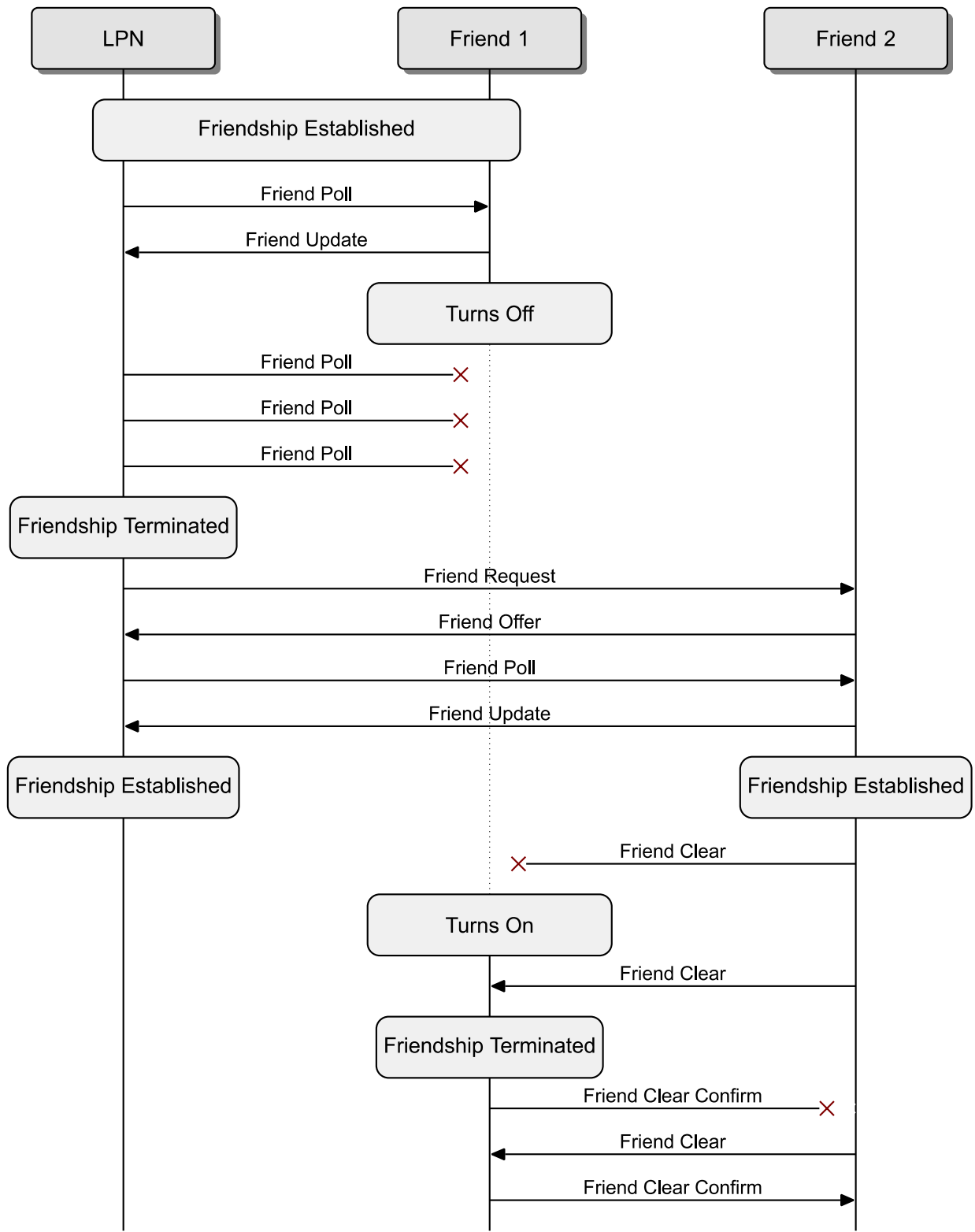


Figure 3.22: Friend Clear procedure example

3.6.6.3.2 *Friend messaging*

When the Friend node receives a Friend Poll message from a friend Low Power node that has the same FSN field value as the last Friend Poll message received from the Low Power node, the Friend node shall respond with exactly the same message it has previously sent, unless that message has been discarded. If the previously sent message has been discarded, then the oldest entry in the Friend Queue shall be sent.

When the Friend node receives a Friend Poll message from a friend Low Power node that has a different FSN field value as the last Friend Poll message from the Low Power node, then it shall send the oldest message from the Friend Queue.

When sending a stored message to the Low Power node, it shall be sent unchanged. If the IV Index on the Friend node has changed, for example the node is now transmitting with a new IV Index, the messages sent to the Low Power node shall still be sent in the context of the IV Index that the Friend node received for those messages.

Note: The above requirement implies that a Low Power node should collect all stored messages at least once every 96 hours, otherwise the Friend node may discard the stored messages before the Low Power node can receive them.

Each message shall be sent after a minimum of ReceiveDelay milliseconds and before a maximum of the sum of ReceiveDelay and ReceiveWindow milliseconds, from the reception of the Friend Poll message from a friend Low Power node.

If no Friend Poll, Friend Subscription List Add, or Friend Subscription List Remove messages are received by the Friend node before the PollTimeout timer expires, the friendship is terminated and the Friend node shall discard all entries in the Friend Queue.

The Friend Subscription List Confirm message shall be sent after a minimum of ReceiveDelay milliseconds and before a maximum of the sum of ReceiveDelay and ReceiveWindow milliseconds, from the reception of the Friend Subscription List Add message or the Friend Subscription List Remove message.

When a Friend node receives a Friend Clear message where the LPNAddress field is a friend Low Power node, and the LPNCounter field is within the range defined in (Section 3.6.5.6), the friendship is terminated and the Friend node shall discard all entries in the Friend Queue.

3.6.6.3.3 *Friend management*

If the Friend node receives a Friend Subscription List Add message (see Section 3.6.5.7) from the Low Power node, it shall add the address or list of addresses contained in the message into the Friend Subscription List and respond with a Friend Subscription List Confirm message (see Section 3.6.5.9) setting the value of the TransactionNumber field to the same value as in the received Friend Subscription List Add message.

If the Friend node receives a Friend Subscription List Remove message (see Section 3.6.5.8) from the Low Power node, it shall remove the address or list of addresses contained in the message from the Friend Subscription List and respond with a Friend Subscription List Confirm message setting the value of

the TransactionNumber field to the same value as in the received Friend Subscription List Remove message.

The Friend node shall respond with a Friend Update message after a minimum of ReceiveDelay milliseconds and before a maximum of the sum of ReceiveDelay and ReceiveWindow milliseconds, from the reception of the Friend Poll message from the Low Power node.

3.6.6.4 Low Power feature

A node that supports the Low Power feature shall support the three mandatory operations: Low Power establishment, Low Power messaging, and Low Power management.

All transport control messages originated by a Low Power node shall be sent as Unsegmented Control messages with the SRC field set to the unicast address of the primary element of the node that supports the Low Power feature.

3.6.6.4.1 Low Power establishment

The Low Power establishment operation is used to establish friendship between a node supporting the Low Power feature and a node supporting the Friend feature.

This operation is started by sending a Friend Request message.

The Friend Request message shall be sent with the TTL set to 0 and the DST field set to the all-friends address. The node shall keep a Low Power node counter (LPNCounter), which is a 2-octet value initialized to 0. This value shall be sent in the Friend Request message and used to derive the friendship security material if a friendship is established as a result of the Friend Request message. After each Friend Request message is sent, this value shall be incremented by 1. The LPNCounter may wrap.

After 100 milliseconds have passed from the Friend Request, the node should listen for up to 1 second for the Friend Offer messages sent by potential Friend nodes, and it may select one of the Friend nodes to establish a friendship. The Low Power node may accept a received Friend Offer or continue to listen for other Friend Offer messages for comparison.

If no acceptable Friend Offer message is received, the node may send a new Friend Request message. The time interval between two consecutive Friend Request messages shall be greater than 1.1 seconds.

To establish a friendship with a potential Friend that has sent a Friend Offer message, the node shall set the Friend Sequence Number to zero and send a Friend Poll message to the selected Friend node within 1 second after the reception of the Friend Offer message. If a Friend Update message is received in response, the friendship is established, the Low Power feature of the node supporting it is in use and the Friend feature of the node supporting it is in use.

The node should restart the Low Power Establishment operation if it does not receive a Friend Update message after several attempts (e.g., 6 attempts).

Multiple failures of the Low Power Establishment operation may be an indication that the Low Power node no longer has a valid IV Index and it should initiate the IV Index Recovery procedure (see Section 3.10.6).



Once friendship has been established the Low Power node shall communicate with the Friend node as defined in Low Power messaging (see Section 3.6.6.4.2) and may manage the friendship as defined in Low Power management (see Section 3.6.6.4.3).

3.6.6.4.2 *Low Power messaging*

The Low Power messaging operation is executed by a Low Power node to receive stored messages and security updates from the Friend node.

The operation consists of asynchronous requests from the Low Power node to the Friend node and timed responses from the Friend node to the Low Power node.

A Low Power node that is friends with a Friend node shall send a Friend Poll message to the Friend node before the PollTimeout timer expires.

In a Friend Poll message, the TTL field shall be set to 0.

As a general rule, the Low Power node should continue sending Friend Poll messages until it receives a Friend Update message with the MD field set to 0. This is illustrated in Figure 3.23.

The Low Power node may terminate friendship with a Friend by sending a Friend Clear. The Friend Clear message should be sent using a TTL of 0.

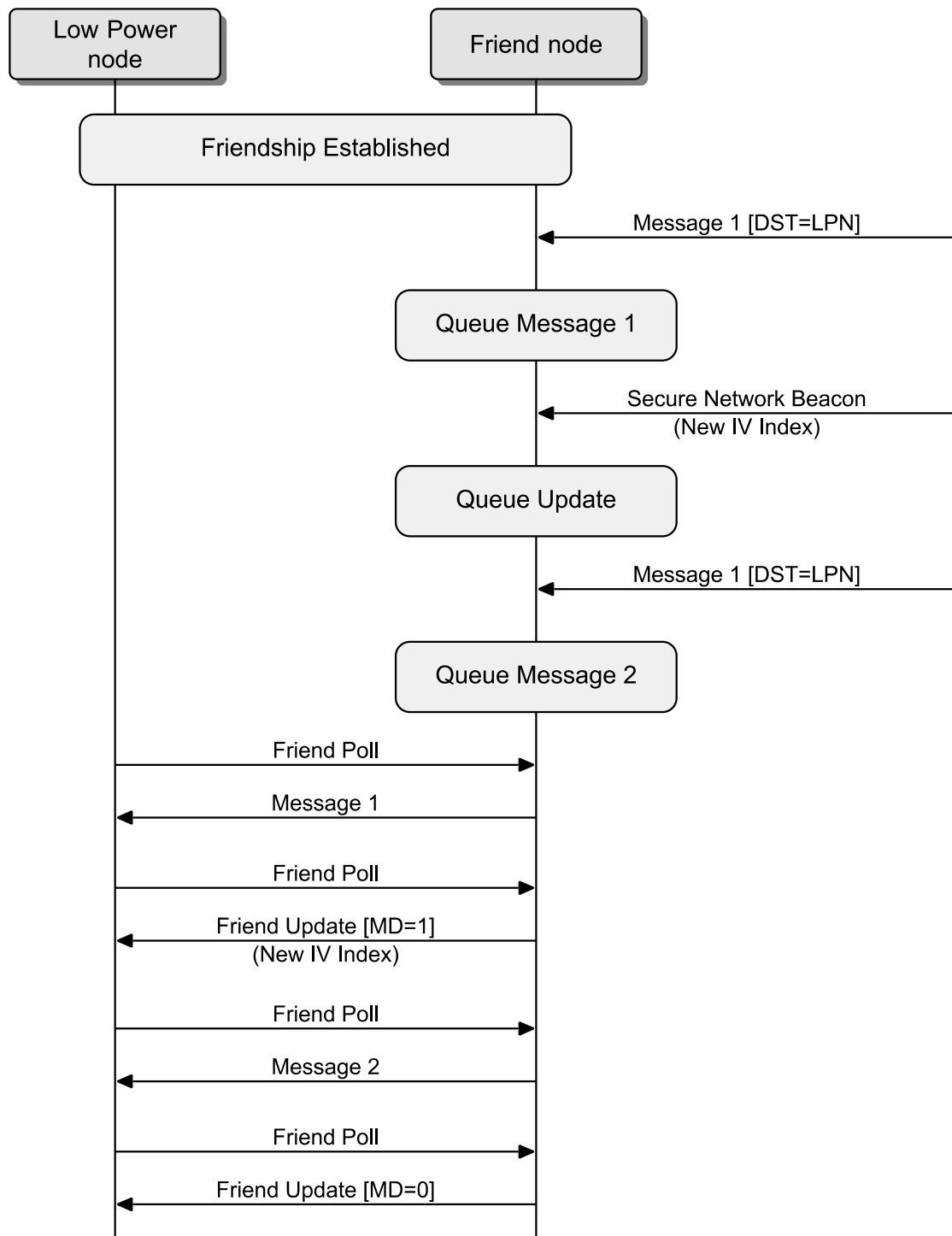


Figure 3.23: Friend Update with security updates

The FSN field shall be set to the value of the Friend Sequence Number.

If the Low Power node receives a response from the Friend node, and the response is not a duplicate of the last received Lower Transport PDU, it shall toggle the Friend Sequence Number.

If the Low Power node does not receive a response within the ReceiveWindow, it should resend the Friend Poll message. It is recommended to resend this message 3 times, which assures a good balance between reliability and power consumption.

If no response has been received to multiple Friend Poll messages before the PollTimeout timer expires, the friendship is terminated. The Low Power node may repeat the Low Power establishment operation.

If the Low Power node receives a Friend Update message, it shall process the Flags and IV Index fields using the same rules as if they had been received in a Secure Network beacon (see Sections 3.9.3.1, 3.10.4, and 3.10.5).

3.6.6.4.3 Low Power management

The Low Power management operation is used to manage the subscription list in a Friend node.

The Low Power node may send one or more Friend Subscription List Add messages to the Friend node containing lists of group addresses or virtual addresses to which the Low Power node is subscribed. This type of message may be sent at any time by the Low Power node when its subscriptions change.

The Low Power node may send one or more Friend Subscription List Remove messages to the Friend node containing lists of group addresses or virtual addresses to which the Low Power node is no longer subscribed. This type of message may be sent at any time by the Low Power node when its subscriptions change.

The Low Power node shall start with a TransactionNumber value set to 0x00. It shall increment the TransactionNumber for each new Friend Subscription List Add or Friend Subscription List Remove such that the TransactionNumber can be matched with the TransactionNumber field of the Friend Subscription List Confirm message.

3.6.6.5 Examples of segmentation and reassembly

The segmentation and reassembly behaviors defined in Sections 3.5.3.3 and 3.5.3.4 also apply to segmented messages sent to and from a Low Power node. The only difference is that since the Low Power node relies on the Friend Queue for all incoming messages, including segments and segment acknowledgments, the Friend node will acknowledge segmented transactions for the Low Power node.

This section provides two examples of segmentation and reassembly on the Low Power node.

3.6.6.5.1 Incoming segmented message

The message sequence chart (MSC) in Figure 3.24 is an example of a segmented message directed toward a Low Power node. The Friend node performs the reassembly separately and sends the acknowledgments needed until it receives all segments, at which point the Friend node places the segments in the Friend Queue so that they can be delivered to the Low Power node. An unsegmented message from another source is received in the middle of the transaction and is handled independently.

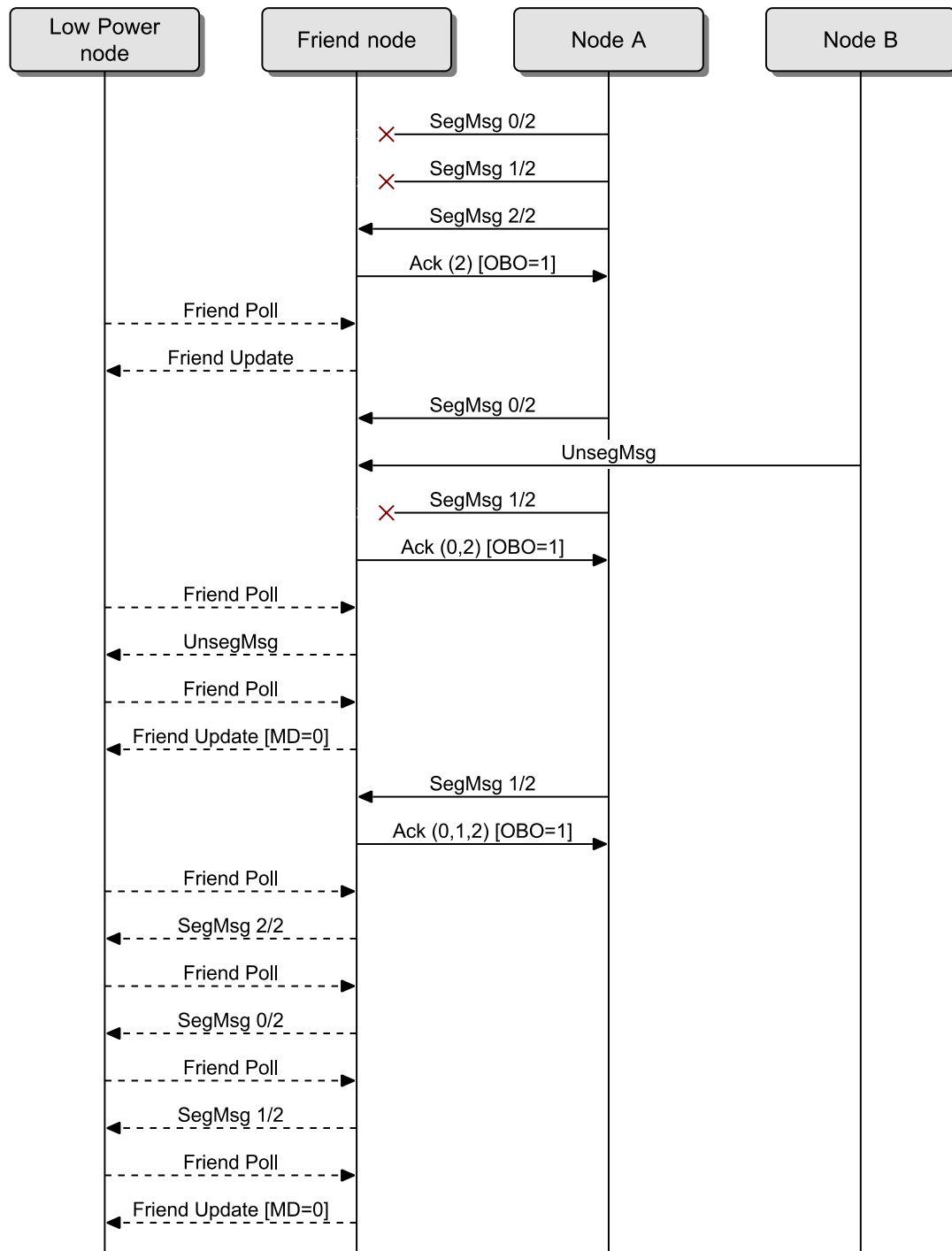


Figure 3.24: Example of incoming segmented message directed to a Low Power node

3.6.6.5.2 Outgoing segmented message

The MSC illustrated in Figure 3.25 shows an example of a segmented message sent by the Low Power node. Since the Low Power node relies on the Friend Queue for all incoming messages, it needs to poll for the acknowledgment as well. An unsegmented message from another source is received in the middle of the transaction and is handled independently.

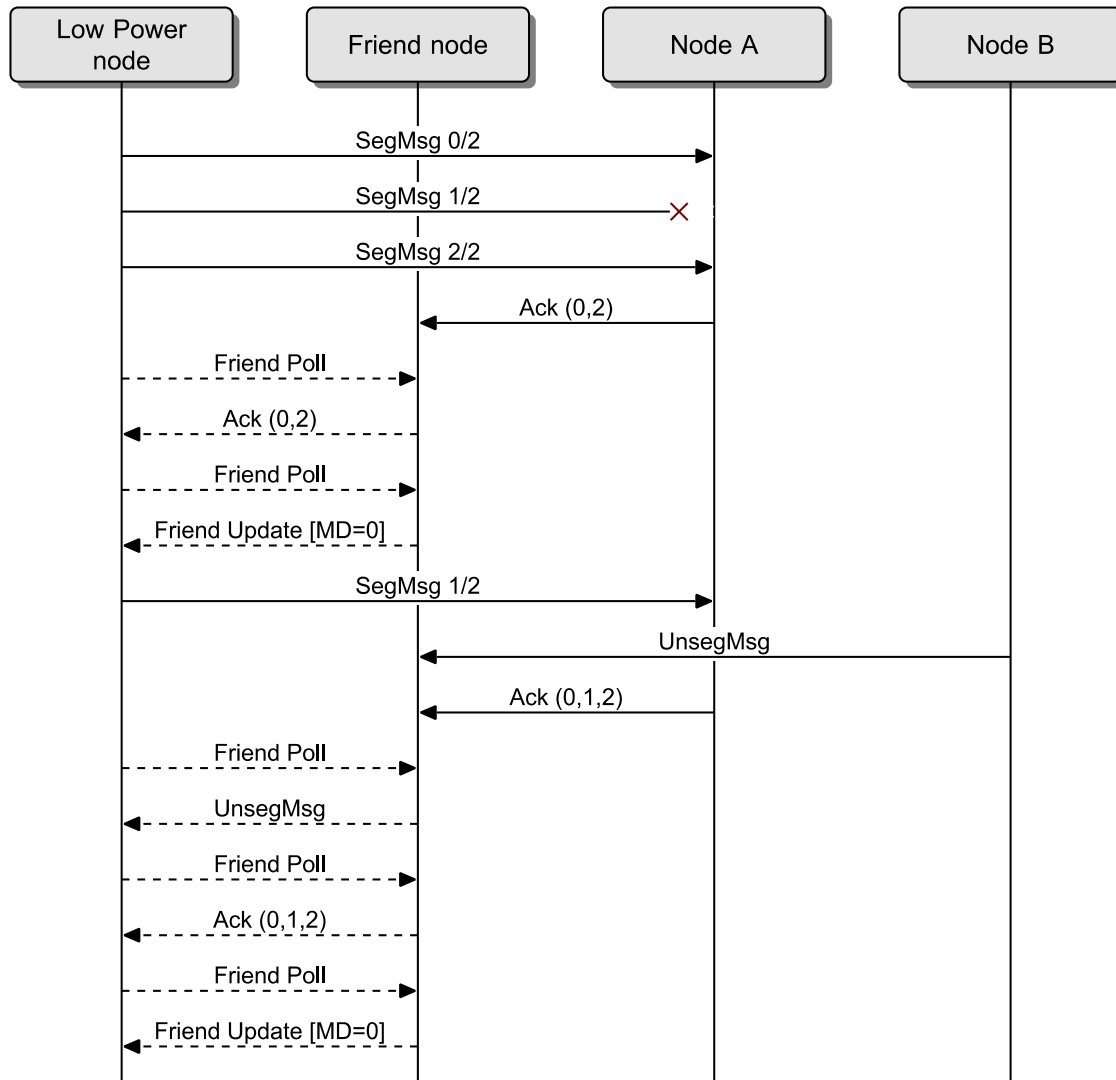


Figure 3.25: Example of outgoing segmented message sent by a Low Power node

3.6.7 Heartbeat

Heartbeat is used to monitor nodes on a network and discover how far nodes are apart from each other.

3.6.7.1 Functional overview

In order to determine if a node is still present and active within a mesh network, it is necessary to receive a message from this node. Sending a message to each and every node in the mesh network to elicit a

response would be very wasteful of energy, and therefore each node can be configured to send a single message periodically. This message is called the Heartbeat message.

The Heartbeat message can be used for two main functions. The first function is the determination that a node is still active within a mesh network. The second function is the determination of how far a node is away.

The Heartbeat message is sent periodically, as configured by the Configuration Server model. The Heartbeat message can be sent a limited number of times or they can be sent indefinitely. Heartbeat messages are sent to a configured destination, and it is recommended that a group address is used for sending Heartbeat messages. The messages can also be configured with a specific TTL value.

When Heartbeat messages are received, they are counted. The number of Heartbeat messages received can help determine the reliability of the mesh network for delivering messages from the node sending Heartbeat messages.

Each Heartbeat message includes the initial TTL value used when sending the original Heartbeat message. This allows a receiving device to determine the number of times this message was retransmitted, known as the number of hops, and a record of the minimum and maximum number of hops can also be used to determine how reliable the mesh network is.

The use of Heartbeat messages can therefore be used to determine the best TTL value to use to address a given node.

Heartbeat messages also include the features of the node that are currently in use. A node can be configured to send a Heartbeat message when various features are enabled or disabled. This allows the features available on various nodes within a mesh network to be determined.

3.6.7.2 Publishing Heartbeat messages

Publishing of Heartbeat messages is controlled by the Heartbeat Publication state (see Section 4.2.17).

When the Heartbeat Publication Destination (see Section 4.2.17.1) address is set to an unassigned address, Heartbeat messages shall not be published. When the value of the Heartbeat Publication Count state (see Section 4.2.17.2) is 0x0000, periodic Heartbeat messages shall not be published.

Heartbeat messages shall be published with the DST field set to the value of the Heartbeat Publication Destination state and with the TTL field set to the value of the Heartbeat Publication TTL state (see Section 4.2.17.4).

Periodic publishing of Heartbeat messages is enabled by the Heartbeat Publication Count state (see Section 4.2.17.2). After publishing a Heartbeat message, if the Heartbeat Publication Count counter is less than 0xFFFF, the Heartbeat Publication Count counter shall be decreased by 1. The counter shall stop at 0x0000. The first Heartbeat message shall be published as soon as possible after the Heartbeat Publication Period state (see Section 4.2.17.3) has been configured for periodic publishing. The next Heartbeat message shall be published after the number of seconds defined by the Heartbeat Publication Period state (see Section 4.2.17.3).

Triggered publishing of Heartbeat messages is enabled by the Heartbeat Publication Features state (see Section 4.2.17.5):

- If the Relay bit is set to 1, a Heartbeat message shall be published when the Relay state of a node (see Section 4.2.8) changes.
- If the Proxy bit is set to 1, a Heartbeat message shall be published when the GATT Proxy state of a node (see Section 4.2.11) changes.
- If the Friend bit is set to 1, a Heartbeat message shall be published when the Friend state of a node (see Section 4.2.13) changes.
- If the Low Power bit is set to 1, a Heartbeat message shall be published when the node establishes or loses Friendship (see Section 3.6.6.1).

3.6.7.3 Receiving Heartbeat messages

Receiving of Heartbeat messages is controlled by the Heartbeat Subscription state (see Section 4.2.18).

The Heartbeat Subscription Period state is a countdown timer identifying the number of seconds remaining for the period when Heartbeat messages are received. When the timer reaches a value of 0x0000, the receiving of Heartbeat messages shall be disabled.

Heartbeat messages with the SRC field set to a value other than the Heartbeat Subscription Source state (see Section 4.2.18.1) or the DST field set to a value other than the Heartbeat Subscription Destination state (see Section 4.2.18.2) shall not be processed.

Upon receiving a Heartbeat message, the value of the Heartbeat Subscription Count state (see Section 4.2.18.3) shall be increased. The counter does not wrap. It stops counting at 0xFFFF.

Upon receiving the Heartbeat message, a hops value shall be calculated using the InitTTL value from the message, and the received Network PDU TTL field value, known as RxTTL, as follows:

$$\text{hops} = \text{InitTTL} - \text{RxTTL} + 1$$

Note: If the message is received directly (for example, the InitTTL value and the received Network PDU TTL field value are the same), then the hops value would be 0x01. If the message has been delivered using the maximum length path, then InitTTL would be 0x7F and the received Network PDU TTL field value would be 0x01, and therefore hops would be 0x7F.

If the hops value is lower than the Heartbeat Subscription Min Hops state, it shall be set as the new value of the Heartbeat Subscription Min Hops state. If the hops value is higher than the Heartbeat Subscription Max Hops state, it shall be set as the new value of the Heartbeat Subscription Max Hops state.

3.7 Access layer

The access layer defines how higher-layer applications can use the upper transport layer. It defines the format of the application data; it defines and controls the application data encryption and decryption performed in the upper transport layer; and it checks whether the incoming application data has been received in the context of the right network and application keys before forwarding it to the higher layer.



3.7.1 Endianness

All multiple-octet numeric values in this layer shall be “little endian” as described in Section 3.1.1.2.

3.7.2 Model identifier

A model is identified by a unique identifier. The identifier can be 16 bits in length for a Bluetooth SIG adopted model (SIG Model ID) or 32 bits in length for a Vendor Model (Vendor Model ID). See Section 4.4.5 for additional information on SIG Model IDs.

The Vendor Model ID is composed of two values: a 16-bit Bluetooth-assigned Company Identifier [6] and a 16-bit vendor-assigned model identifier. The format of each Vendor Model ID is defined in Table 3.40.

Field	Size (octets)	Notes
16-bit Company Identifier	2	See [6]
16-bit vendor-assigned model identifier	2	

Table 3.40: Vendor Model ID format

3.7.3 Access payload

The access payload is logically composed of the fields shown in Table 3.41.

Field Name	Size (octets)	Notes
Opcode	1, 2, or 3	Operation Code
Parameters	0 to 379	Application Parameters

Table 3.41: Access payload fields

An access payload may be sent in up to 32 segments of 12 octets each. This implies that the maximum number of octets is 384 including the TransMIC.

With a 4-octet TransMIC, the maximum size of the access payload is 380 octets, and therefore with a single octet opcode, the parameters field can be up to 379 octets. With a 2-octet opcode, the parameters field can be up to 378 octets. With a 3-octet opcode, the parameters field can be up to 377 octets.

The lower transport layer may segment messages into smaller PDUs for delivery over the network layer. Table 3.42 shows the maximum useful application packet size depending on the number of packets and the size of the TransMIC.

Number of Packets	Maximum useful access payload size (octets)	
	32 bit TransMIC	64 bit TransMIC
1	11 (unsegmented)	n/a
1	8 (segmented)	4 (segmented)
2	20	16



Number of Packets	Maximum useful access payload size (octets)	
	32 bit TransMIC	64 bit TransMIC
3	32	28
n	$(n \times 12) - 4$	$(n \times 12) - 8$
32	380	376

Table 3.42: Maximum useful access payload sizes for various sizes of TransMIC

3.7.3.1 Operation codes

An operation code (opcode) is an array of octets comprising 1, 2, or 3 octets. The first octet of the opcode determines the number of octets that are part of the opcode.

If the most significant bit of the first octet of the opcode is zero, then the opcode contains a single octet. If the two most significant bits of the first octet are 0b10, then the opcode contains two octets. If the two most significant bits of the first octet are 0b11, then the opcode contains three octets. This is shown in Table 3.43.

Opcode Format	Notes
0xxxxxxx (excluding 01111111)	1-octet Opcodes
01111111	Reserved for Future Use
10xxxxxx xxxxxxxx	2-octet Opcodes
11xxxxxx zzzzzzzz	3-octet Opcodes

Table 3.43: Opcode formats

The 1-octet opcodes are used for Bluetooth SIG defined application opcodes. There are 127 1-octet opcodes that can be defined and allocated by the Bluetooth SIG. Opcode 0x7F is reserved for future possible extension.

The 2-octet opcodes are used for Bluetooth SIG defined application opcodes. There are 16384 2-octet opcodes that can be defined and allocated by the Bluetooth SIG.

The 3-octet opcodes are used for manufacturer-specific opcodes. There are 64 3-octet opcodes available per company identifier, identified using "x" in Table 3.43, although a company may further sub-class opcodes if desired. The company identifiers are 16-bit values defined by the Bluetooth SIG and are coded into the second and third octets of the 3-octet opcodes, identified using "z" in Table 3.43, using endianness as defined in Section 3.7.1. The company-specific opcodes are managed by the company associated with the identifier.

For example, when the manufacturer-specific opcode is equal to 0x23 and the company identifier is equal to 0x0136 [6], then the 3-octet opcode is equal to 0xE3 0x36 0x01.

3.7.3.2 Application parameters

The Parameters field is defined individually for each opcode. The specific parameters are defined within the message definitions in Section 4.3. The Parameters field can be zero octets in length.



3.7.4 Access layer behavior

3.7.4.1 Transmitting an access message

A message is transmitted by a model to a destination address that is a unicast address, a group address, or a virtual address.

A message is transmitted from a source address, which is the transmitting element's unicast address.

The TTL field may be specified by the application by setting it to the number of hops required to transfer the message from the source element to all the destination addresses. However, if this is not specified, the Default TTL shall be applied by the access layer.

The SRC field shall be set to the unicast address of the element within the node that is originating the message.

The DST field shall be set to the unicast address, group address, or virtual address that the message is directed toward.

A higher layer sets the value of the DST field. For example, if the message is published (see Section 3.7.6.1), the Model Publication state (see Section 4.2.2) determines the value of the DST field. An application may also send a message to a destination by specifying the value of the DST field.

The access layer does not guarantee delivery of messages. Each model should decide if a message is to be retransmitted and how potential duplicates are handled.

If the message is sent in response to a received message that was sent to a unicast address, the node should transmit the response message with a random delay between 20 and 50 milliseconds. If the message is sent in response to a received message that was sent to a group address or a virtual address, the node should transmit the response message with a random delay between 20 and 500 milliseconds. This reduces the probability of multiple nodes responding to this message at exactly the same time, and therefore increases the probability of message delivery rather than message collisions.

A node can also be configured to publish a message due to a local state change or to indicate the progress of a transition to a new state or when the transition to the new state has been completed (see Section 3.7.6.1). If the transition to a new state is caused by the user action, the device should send the status message as soon as possible. When the publication of a message is caused by a power up, the transition to a new state progress update, or to indicate the completion of the transition to a new state multiple nodes may be reporting the state change at the same time. To reduce the probability of the collision, these messages should be sent with a random delay between 20 and 500 milliseconds.

Due to limited bandwidth available that is shared among all nodes and other Bluetooth devices, it is important to observe the volume of traffic a node is originating. A node should originate less than 100 Lower Transport PDUs in a moving 10-second window.

3.7.4.2 Receiving an access message

A message is delivered to the model for processing if all the following conditions are met:

- The opcode indicates the message is used by the model on this element.



- The destination address is set to one of the following:
 - the model's element unicast address;
 - a group or virtual address which the model's element is subscribed to;
 - a fixed group address of the primary element of the node as defined in Section 3.4.2.4.
- The model is bound to the application or device key that was used to secure the transportation of the message.

3.7.4.3 Security considerations

A message is encrypted and authenticated by the upper transport layer. Messages originated by a node shall use either the AppKey configured for the Model or the DevKey.

A response message shall always use the same DevKey or AppKey used by the corresponding request message.

3.7.4.4 Message error procedure

When receiving a message that is not understood by an element, it shall ignore the message.

Note: A message can be falsely identified as a valid message, passing the NetMIC and TransMIC authentication using a known network key and application key even though that message was sent using different keys. The decryption of that message using the wrong keys would result in a message that is not understood by the element. The probability of such a situation occurring is small but not insignificant.

A message that is not understood includes messages that have one or more of the following conditions:

- The application opcode is unknown by the receiving element.
- The access message size for the application opcode is incorrect.
- The application parameters contain values that are currently Prohibited.

Note: An element that sends an acknowledged message that is not understood by a peer node will not receive any response message.

3.7.5 Unacknowledged and acknowledged messages

At the access layer, a message is defined as unacknowledged or acknowledged.

3.7.5.1 Unacknowledged message

An unacknowledged message is transmitted when a response is not required.

For example, a message is published by a model when a state changes, or an unacknowledged message may be sent to a group address to change the states of the group members without causing multiple messages to be sent back.

There is no response to an unacknowledged message, therefore it is not possible for the sending element to determine if that message has been delivered or processed.

3.7.5.2 Acknowledged message

An acknowledged message is transmitted and acknowledged by each receiving element by responding to that message. The response is typically a status message.

If a response is not received within an arbitrary time period, the message originator may retransmit the message. The time period used is application specific.

If an element transmits a message to more than one element, for example it has set the destination address to a group address, the element may not know how many elements may respond to the message. It is not recommended to send an acknowledged message to the all-nodes address. To increase the probability of successful delivery of messages, the sending element should determine how many message retransmissions are required before it considers that all the nodes that should have received the message have actually received it.

If the element does not receive a response within a period of time known as the acknowledged message timeout, then the element may consider the message has not been delivered, without sending any additional messages.

The acknowledged message timeout should be set to a minimum of 30 seconds. The exact value is application specific.

When an acknowledged message is delivered to the model, it shall send the associated response message to acknowledge that message. The response message may include information such as state information. The response message is an unacknowledged message. The destination of the response message shall be set to the source address of the received acknowledged message. If the acknowledged message has TTL set to 0, it is recommended that the response message should have TTL set to 0.

3.7.6 Publish and subscribe

A higher layer specification can describe messages containing data as being published by a model or subscribed to by a model's element.

Publishing and subscribing is performed using destination addresses.

The configuration of the destination addresses used for publishing and subscribing is managed by the Foundation models (see Section 4).

3.7.6.1 Publish

A model publishes data if it transmits an unsolicited message to a destination address. Messages can be transmitted to destination addresses that can be unicast, group, or virtual, known as the publish addresses. Each model within a node has a single publish address.

3.7.6.1.1 State transitions

States within an element either can change instantaneously or can transition over time to a new state, as illustrated in Figure 3.26. The time from the initial state to the target state is the transition time. The time from the current state to the target state is the remaining time. When a message is received to set a new state value, this new value may not be immediately applied, but may instead be stored as a target state. The state will transition from the initial state to the target state. A status message can be sent at any time and will always include the current state even if the transition time has not elapsed. This status message may include the remaining time between the current state and the target state. When the current state reaches the target state, the state transition ends.

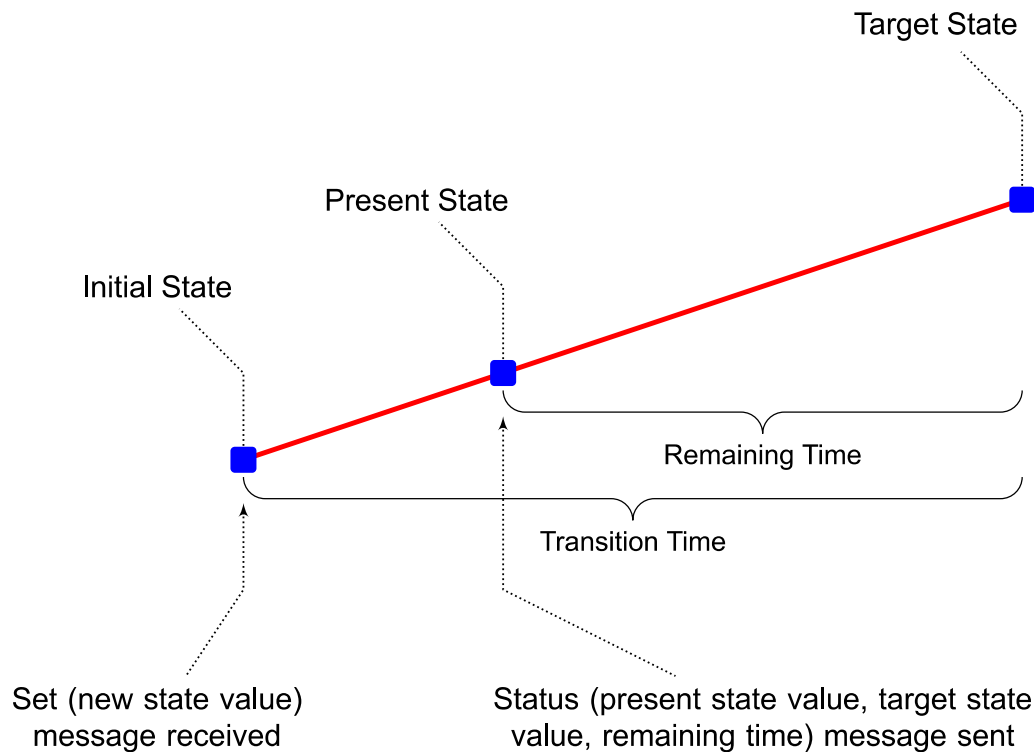


Figure 3.26: State transition

3.7.6.1.2 State change publishing

Publishing a message on a state change is enabled by setting a Model Publication state (see Section 4.2.2) for a model. When publishing is enabled for a model, unless specified otherwise by a higher layer specification, a corresponding status message shall be published immediately after the state transition ends. For transitions that take more than 2 seconds, it is recommended to publish an additional status message within 1 second from the start of the state transition.

3.7.6.1.3 Periodic publishing

A model may be configured to send status messages periodically regardless of whether the state has changed or not. This is done by using a Publish Period (see Section 4.2.2.2). When the Publish Period is set to a non-zero value, unless specified otherwise by a higher layer specification, a status message shall be published at least once every Publish Period. When the Publish Period is set to 0, the status messages shall only be published on a state change when enabled.

3.7.6.1.4 Publish retransmissions

When a new message is being published by a model instance, all pending retransmissions of the previous message published by the model instance shall be canceled, and the model instance shall retransmit the new message as specified by the Publish Retransmit Count and Publish Retransmit Interval Steps states.

3.7.6.2 Subscribe

Each model may have one or more subscription lists (see Section 4.2.3) of one or more addresses that determines which destination addresses this model's element subscribes to. These subscription addresses can be a group address or a virtual address.

Note: A model is, in effect, always subscribed to its element unicast address as described in Section 3.7.4.2.

3.7.7 Example message sequence charts

This section shows typical message sequence charts.

3.7.7.1 Acknowledged get

Figure 3.27 shows a client getting a state of a peer element using an acknowledged get message. The server responds with the associated status message.

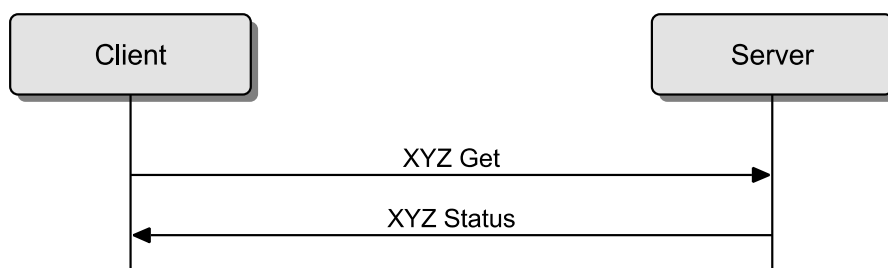


Figure 3.27: Acknowledged get message

3.7.7.2 Acknowledged set

Figure 3.28 shows a client setting a state of a peer element with an acknowledged set message. The server responds with the associated status message. The server then publishes a status message to the model's publish address according to the publishing rules (see Section 3.7.6.1.2). If the client is subscribed to this model's publish address, then it will receive both status messages.

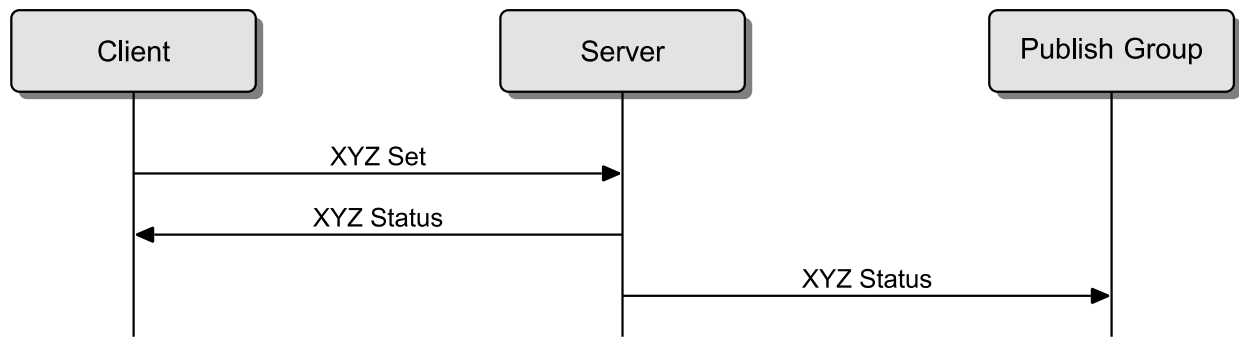


Figure 3.28: Acknowledged set message

3.7.7.3 Unacknowledged set

Figure 3.29 shows a client setting a state of a peer element with an unacknowledged set message. No response is sent, but the server publishes the new state information to the model's publish address according to the publishing rules (see Section 3.7.6.1.2). If the client is subscribed to this model's publish address, then it will receive the status message.

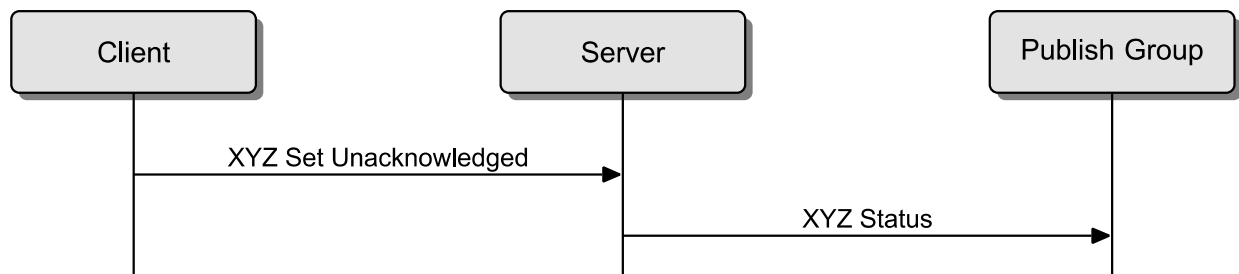


Figure 3.29: Unacknowledged set message

3.7.7.4 Acknowledged set with periodic publishing

Figure 3.30 shows a client setting a state of a peer element with an acknowledged set message. The server responds with the associated status message. The server then periodically publishes the new state information to the model's publish address, according to the periodic publishing rules (see Section 3.7.6.1.2).

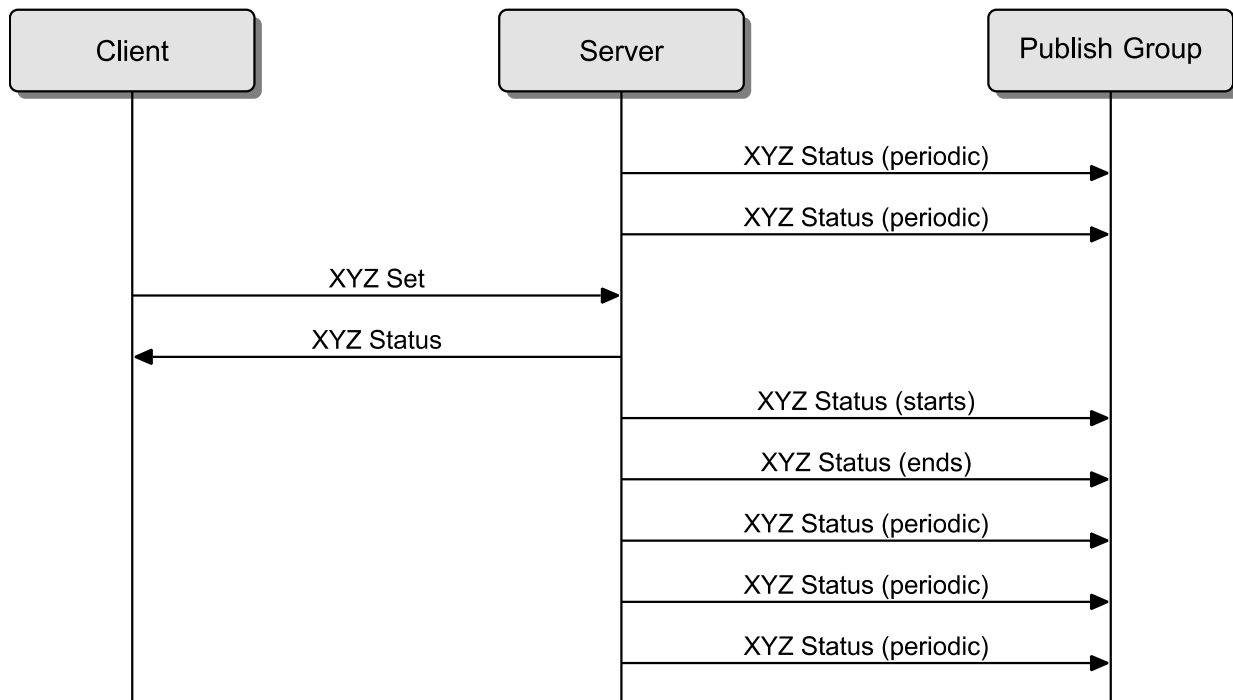


Figure 3.30: Acknowledged set message with periodic publishing

3.8 Mesh security

This section describes how mesh security is implemented.

3.8.1 Endianness

All multiple-octet numeric values in this layer shall be marshalled in “big endian,” as described in Section 3.1.1.1.

3.8.2 Security toolbox

This section describes the eight functions that together provide a security toolbox for mesh networking.

3.8.2.1 Encryption function

The same encryption function e , as defined in Volume 3, Part H, Section 2.2.1 of the Core Specification [1], shall be used. This can be summarized as:

$$\text{ciphertext} = e(\text{key}, \text{plaintext})$$

3.8.2.2 CMAC function

RFC4493 [9] defines the Cipher-based Message Authentication Code (CMAC) that uses AES-128 as the block cipher function, also known as AES-CMAC. The inputs to AES-CMAC are:

k is the 128-bit key

m is the variable length data to be authenticated



The 128-bit message authentication code (MAC) is generated¹ as follows:

$$\text{MAC} = \text{AES-CMAC}_k(m)$$

A node can implement AES functions in the host or can use the HCI_LE_Encrypt command (see Volume 2, Part E, Section 7.8.22 of the Core Specification [1]) in order to use the AES function in the controller.

3.8.2.3 CCM function

RFC3610 [10] defines the AES Counter with CBC-MAC (CCM) (see Volume 6, Part E, Section 1 of the Core Specification [1]). This specification defines AES-CCM as a function that takes four inputs and results in two outputs:

The inputs to AES-CCM are:

k is the 128-bit key

n is a 104-bit nonce

m is the variable length data to be encrypted and authenticated – also known as “plaintext”

a is the variable length data to be authenticated – also known as “Additional Data”

The ciphertext and mic are generated as follows:

$$\text{ciphertext, mic} = \text{AES-CCM}_k(n, m, a)$$

Where:

ciphertext is the variable length data after it has been encrypted

mic is the message integrity check value of m and a – also known as the “Message Authentication Code” or the encrypted authentication value U in RFC3610 [10].

If only the k, n, and m parameters are provided to the AES-CCM, then the additional data shall be zero length.

3.8.2.4 s1 SALT generation function

The inputs to function s1 are:

M is a non-zero length octet array or ASCII encoded string

¹ This is using the same notation used in other Bluetooth specifications. This is functionally the same as the notation as RFC 4493, where $\text{MAC} = \text{AES-CMAC}(k, m)$.

If M is an ASCII encoded string, it shall be converted into an octet array by replacing each string character with its ASCII code preserving the order. For example, if M is the string “MESH”, this is converted into the octet array: 0x4d, 0x45, 0x53, 0x48.

ZERO is the 128-bit value:

0x0000 0000 0000 0000 0000 0000 0000 0000

The output of the salt generation function s1 is as follows:

$$s1(M) = \text{AES-CMAC}_{\text{ZERO}}(M)$$

3.8.2.5 k1 derivation function

The network key material derivation function k1 is used to generate instances of IdentityKey and BeaconKey.

The definition of this key generation function makes use of the MAC function AES-CMAC_T with a 128-bit key T.

The inputs to function k1 are:

N is 0 or more octets

SALT is 128 bits

P is 0 or more octets

The key (T) is computed as follows:

$$T = \text{AES-CMAC}_{\text{SALT}}(N)$$

The output of the key generation function k1 is as follows:

$$k1(N, \text{SALT}, P) = \text{AES-CMAC}_T(P)$$

3.8.2.6 k2 network key material derivation function

The network key material derivation function k2 is used to generate instances of EncryptionKey, PrivacyKey, and NID for use as Master and Private Low Power node communication.

The definition of this key generation function makes use of the MAC function AES-CMAC_T with a 128-bit key T.

The inputs to function k2 are:

N is 128 bits

P is 1 or more octets

The key (T) is computed as follows:

$$T = \text{AES-CMAC}_{\text{SALT}}(N)$$

SALT is the 128-bit value computed as follows



$$\text{SALT} = \text{s1}(\text{"smk2"})$$

The output of the key generation function k2 is as follows:

$$\begin{aligned} T0 &= \text{empty string (zero length)} \\ T1 &= \text{AES-CMAC}_T(T0 \parallel P \parallel 0x01) \\ T2 &= \text{AES-CMAC}_T(T1 \parallel P \parallel 0x02) \\ T3 &= \text{AES-CMAC}_T(T2 \parallel P \parallel 0x03) \\ k2(N, P) &= (T1 \parallel T2 \parallel T3) \bmod 2^{263} \end{aligned}$$

3.8.2.7 k3 derivation function

The derivation function k3 is used to generate a public value of 64 bits derived from a private key.

The definition of this derivation function makes use of the MAC function AES-CMAC_T with a 128-bit key T.

The inputs to function k3 are:

N is 128 bits

The key (T) is computed as follows:

$$T = \text{AES-CMAC}_{\text{SALT}}(N)$$

SALT is a 128-bit value computed as follows:

$$\text{SALT} = \text{s1}(\text{"smk3"})$$

The output of the derivation function k3 is as follows:

$$k3(N) = \text{AES-CMAC}_T(\text{"id64"} \parallel 0x01) \bmod 2^{64}$$

3.8.2.8 k4 derivation function

The derivation function k4 is used to generate a public value of 6 bits derived from a private key.

The definition of this derivation function makes use of the MAC function AES-CMAC_T with a 128-bit key T.

The inputs to function k4 are:

N is 128 bits

The key (T) is computed as follows:

$$T = \text{AES-CMAC}_{\text{SALT}}(N)$$

SALT is a 128-bit value computed as follows:

$$\text{SALT} = \text{s1}(\text{"smk4"})$$

The output of the derivation function k4 is as follows:

$$K4(N) = \text{AES-CMAC}_T(\text{"id6"} \parallel 0x01) \bmod 2^6$$



3.8.3 Sequence number

The sequence number, a 24-bit value contained in the SEQ field of the Network PDU, is primarily designed to protect against replay attacks. Elements within the same node may or may not share the sequence number space with each other. Having a different sequence number in each new Network PDU for every message source (identified by the unicast address contained in the SRC field) is critical for the security of the mesh network.

With a 24-bit sequence number, an element can transmit 16,777,216 messages before repeating a nonce. If an element transmits a message on average once every five seconds (representing a fairly high frequency message for known use cases), the element can transmit for 2.6 years before the nonce repeats.

Each element shall use strictly increasing sequence numbers for the Network PDUs it generates. Before the sequence number approaches the maximum value (0xFFFFF), the element shall update the IV Index using the IV Update procedure (see Section 3.10.5). This is done to ensure that the sequence number will never wrap around.

3.8.4 IV Index

The IV Index is a 32-bit value that is a shared network resource (i.e., all nodes in a mesh network share the same value of the IV Index and use it for all subnets they belong to).

The IV Index starts at 0x00000000 and is incremented during the IV Update procedure as described in Section 3.10.5. The timing when the value is incremented does not have to be exact, since the least significant bit is communicated within every Network PDU. Since the IV Index value is a 32-bit value, a mesh network can function approximately 5 trillion years before the IV Index will wrap.

The IV Index is shared within a network via Secure Network beacons (see Section 3.9.3). IV updates received on a subnet are processed and propagated to that subnet. The propagation happens by the device transmitting Secure Network beacons with the updated IV Index for that particular subnet. If a device on a primary subnet receives an update on the primary subnet, it shall propagate the IV update to all other subnets. If a device on a primary subnet receives an IV update on any other subnet, the update shall be ignored.

If a node is absent from a mesh network for a period of time, it can scan for Secure Network beacons (see Section 3.10.1) or use the IV Index Recovery procedure (see Section 3.10.6), and therefore set the IV Index value autonomously.

3.8.5 Nonce

The nonce is a 13-octet value that is unique for each new message encryption. There are four different nonces that are used, as shown in Table 3.44. The type of the nonce is determined by the first octet of the nonce, referred to as the Nonce Type.



Nonce Type	Nonce	Description
0x00	Network nonce	Used with an encryption key for network authentication and encryption
0x01	Application nonce	Used with an application key for upper transport authentication and encryption
0x02	Device nonce	Used with a device key for upper transport authentication and encryption
0x03	Proxy nonce	Used with an encryption key for proxy authentication and encryption
0x04–0xFF	RFU	Reserved for Future Use

Table 3.44: Nonce types

Note: The TTL is used within the network nonce but not within the application nonce, device nonce, or proxy nonce. This means that when a message is relayed and the TTL is decremented, the application nonce or device nonce does not change; however, the network nonce does change, allowing the authentication of the TTL value.

Note: The DST is used within the application nonce and device nonce but not in the network nonce. This means that the destination of the application or device message may be authenticated, but at the network layer the destination address is encrypted.

3.8.5.1 Network nonce

The network nonce is defined in Table 3.45 and illustrated in Figure 3.31.

Field	Size (octets)	Notes
Nonce Type	1	0x00
CTL and TTL	1	See Table 3.46
SEQ	3	Sequence Number
SRC	2	Source Address
Pad	2	0x0000
IV Index	4	IV Index

Table 3.45: Network nonce format

Field	Size (bits)	Notes
CTL	1	See Section 3.4.4.3
TTL	7	See Section 3.4.4.4

Table 3.46: CTL and TTL field format



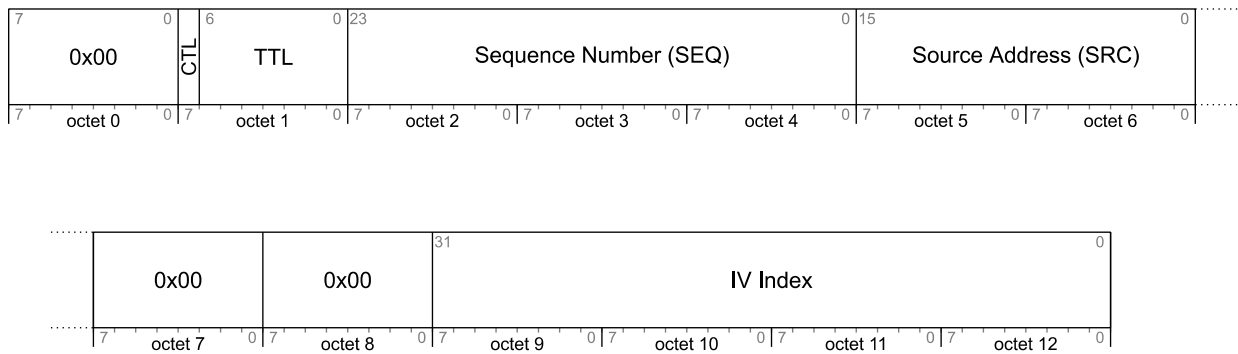


Figure 3.31: Network nonce format

The network nonce is used with an encryption key for network data authentication and encryption (see Section 3.8.7.2).

3.8.5.2 Application nonce

The application nonce is defined in Table 3.47 and illustrated in Figure 3.32.

Field	Size (octets)	Notes
Nonce Type	1	0x01
ASZMIC and Pad	1	See Table 3.48
SEQ	3	Sequence Number of the Access message (24 lowest bits of SeqAuth in the context of segmented messages)
SRC	2	Source Address
DST	2	Destination Address
IV Index	4	IV Index

Table 3.47: Application nonce format

Field	Size (bits)	Notes
ASZMIC	1	SZMIC if a Segmented Access message or 0 for all other message formats
Pad	7	0b0000000

Table 3.48: ASZMIC and Pad field format

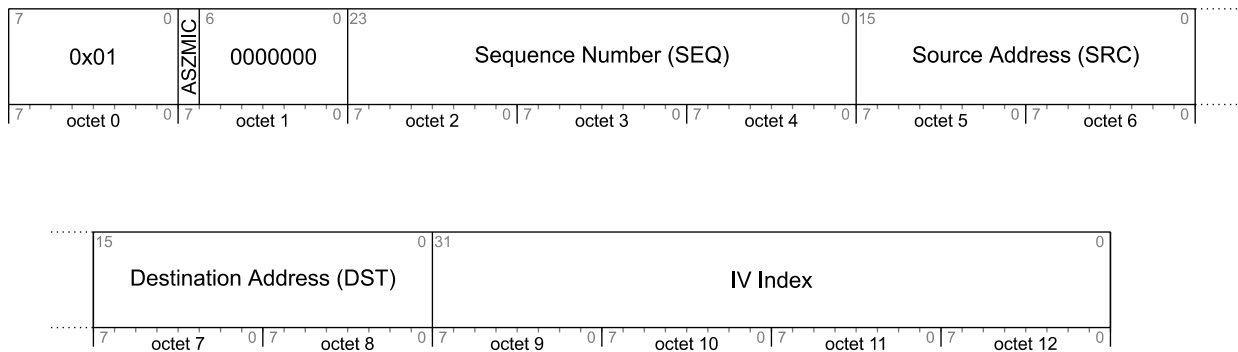


Figure 3.32: Application nonce format

The application nonce is used with an application key for application data authentication and encryption (see Section 3.8.6).

3.8.5.3 Device nonce

The device nonce is defined in Table 3.49 and illustrated in Figure 3.33.

Field	Size (octets)	Notes
Nonce Type	1	0x02
ASZMIC and Pad	1	See Table 3.50
SEQ	3	Sequence Number of the Access message (24 lowest bits of SeqAuth in the context of segmented messages)
SRC	2	Source Address
DST	2	Destination Address
IV Index	4	IV Index

Table 3.49: Device nonce format

Field	Size (bits)	Notes
ASZMIC	1	SZMIC if a Segmented Access message or 0 for all other message formats
Pad	7	0b0000000

Table 3.50: ASZMIC and Pad field format



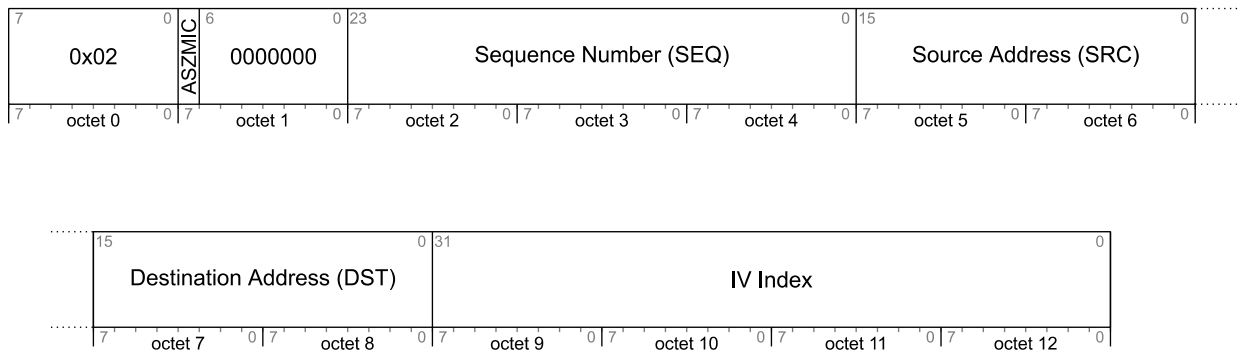


Figure 3.33: Device nonce format

The device nonce is used with a device key for application data authentication and encryption specific for a given device (see Section 3.8.6).

3.8.5.4 Proxy nonce

The proxy nonce is defined in Table 3.51 and illustrated in Figure 3.34.

Field	Size (octets)	Notes
Nonce Type	1	0x03
Pad	1	0x00
SEQ	3	Sequence Number
SRC	2	Source Address
Pad	2	0x0000
IV Index	4	IV Index

Table 3.51: Proxy nonce format

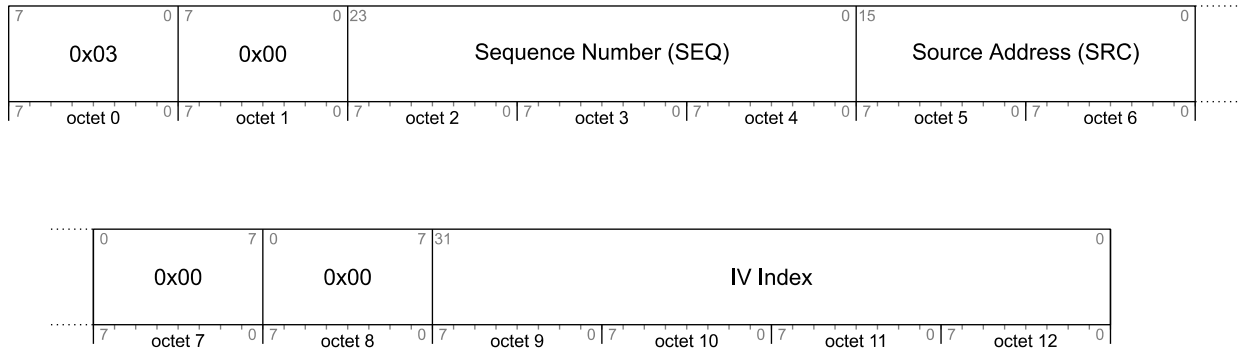


Figure 3.34: Proxy nonce format

The proxy nonce is used with an encryption key for proxy configuration message authentication and encryption (see Section 6.5).

3.8.6 Keys

The Mesh Profile specification defines two types of keys: application keys (AppKey) and network keys (NetKey). AppKeys are used to secure communications at the upper transport layer and NetKeys are used to secure communications at the network layer. Both types of keys are shared between nodes. There is also a device key (DevKey), which is a special application key that is unique to each node, is known only to the node and a Configuration Client, and is used to secure communications between the node and a Configuration Client.

Application keys are bound to network keys. This means application keys are only used in a context of a network key they are bound to. An application key shall only be bound to a single network key. A device key is implicitly bound to all network keys.

An example of binding application keys to network keys and models is illustrated in [Figure 3.35](#).

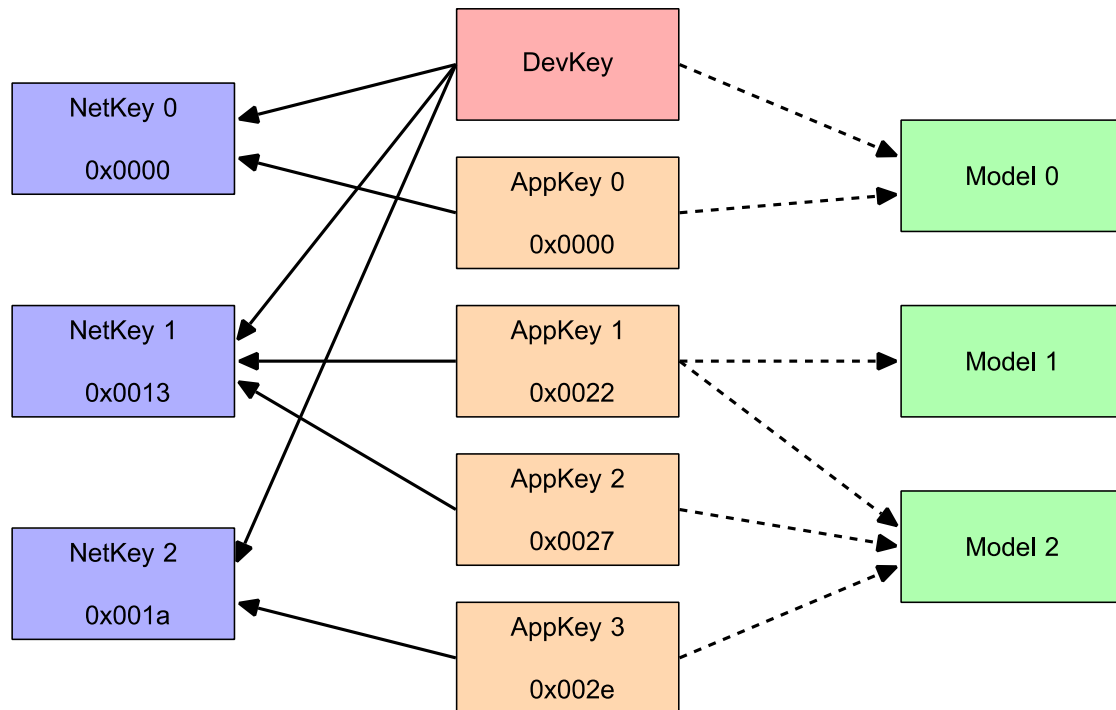


Figure 3.35: Application key binding example

3.8.6.1 Device key

The device key (DevKey) is an access layer key known only to the node and a Configuration Client. The device key shall be bound to every network key known to the node. Those bindings cannot be changed. An illustration of the device key derivation is shown in [Figure 3.36](#).

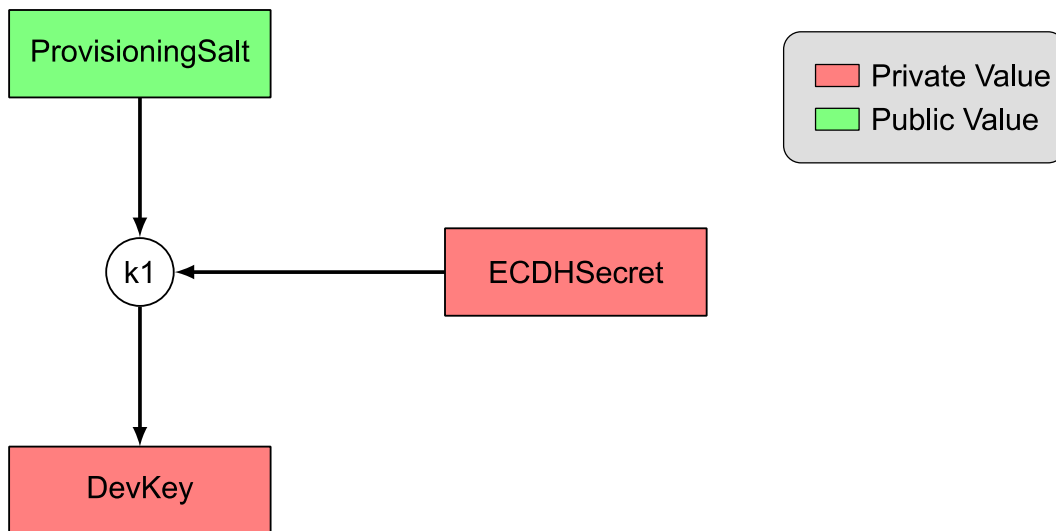


Figure 3.36: Device key derivation

The DevKey shall be derived from the ECDHSecret and ProvisioningSalt as described by the formula below:

$$\text{DevKey} = k1(\text{ECDHSecret}, \text{ProvisioningSalt}, \text{"prdk"})$$

The ProvisioningSalt is defined in Section 5.4.2.5 and the ECDHSecret is defined in Section 5.4.2.3.

3.8.6.2 Application key

The application key (AppKey) shall be generated using a random number generator compatible with the requirements in Volume 2, Part H, Section 2 of the Core Specification [1].

The application key identifier (AID) is used to identify the application key. An illustration of the AID derivation is shown in Figure 3.37.

$$\text{AID} = k4(\text{AppKey})$$

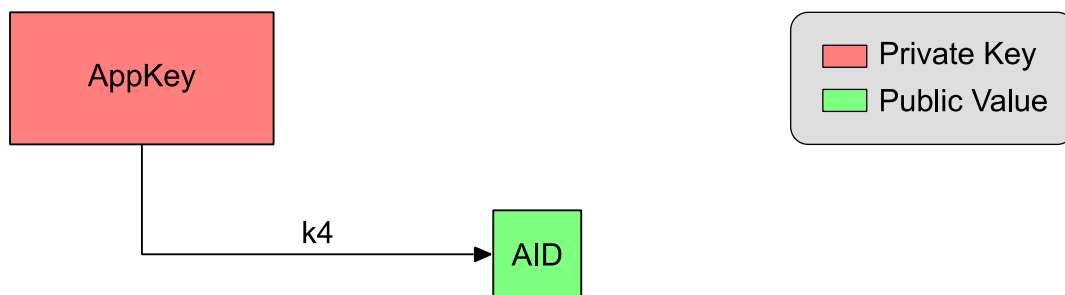


Figure 3.37: AID derivation

3.8.6.3 Network key

The network key (NetKey) shall be generated using a random number generator compatible with the requirements in Volume 2, Part H, Section 2 of the Core Specification [1]. An illustration of the network key hierarchy is shown in Figure 3.38.

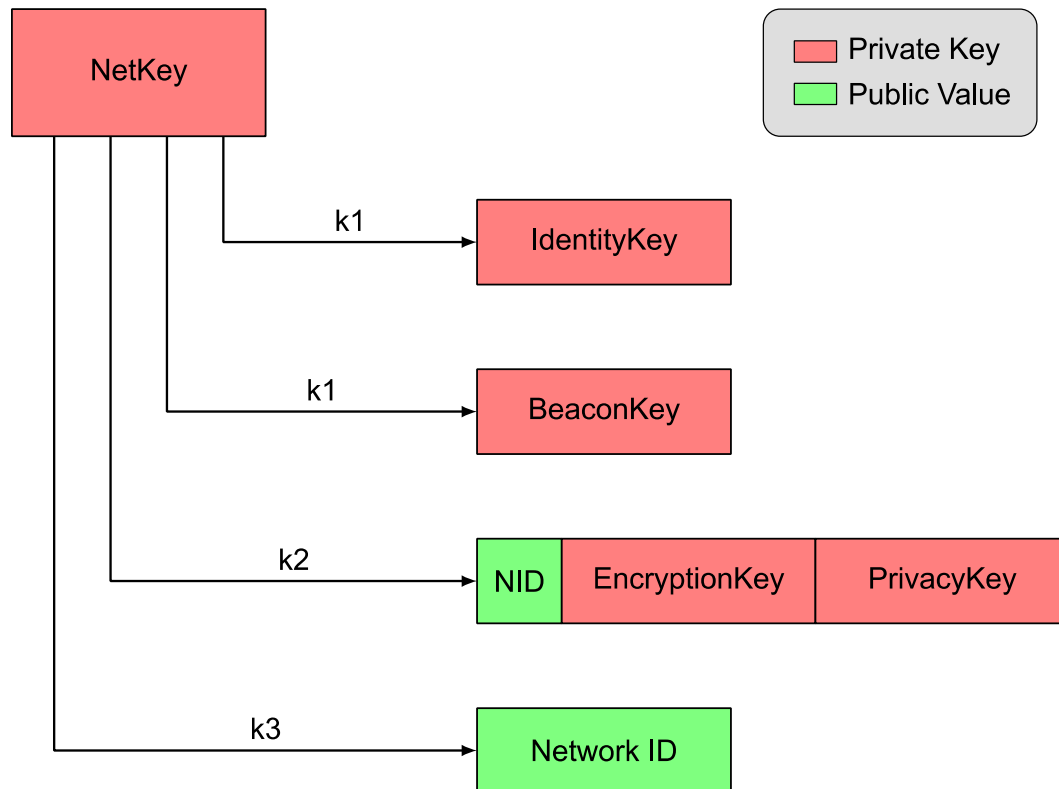


Figure 3.38: Network key hierarchy

3.8.6.3.1 NID, Encryption Key, and Privacy Key

Each Network PDU is secured using security material that is composed of the NID, the Encryption Key, and the Privacy Key.

The NID is a 7-bit value that identifies the security material that is used to secure this Network PDU.

Note: There are up to 2^{121} possible keys for each NID; therefore, the NID value can only provide an indication of the security material that has been used to secure this Network PDU.

The NID, EncryptionKey, and PrivacyKey are derived using the k2 function with security credentials as inputs.

The master security material is derived from the master security credentials using:

$$\text{NID} \parallel \text{EncryptionKey} \parallel \text{PrivacyKey} = k2(\text{NetKey}, 0x00)$$

The friendship security material is derived from the friendship security credentials using:

$$\text{NID} \parallel \text{EncryptionKey} \parallel \text{PrivacyKey} = \text{k2}(\text{NetKey}, 0x01 \parallel \text{LPNAddress} \parallel \text{FriendAddress} \parallel \text{LPNCounter} \parallel \text{FriendCounter})$$

Where:

The LPNAddress value is the unicast address set as source address in the Friend Request message that set up the friendship.

The FriendAddress value is the unicast address set as source address in the Friend Offer message that set up the friendship.

The LPNCounter value is the value from the LPNCounter field of the Friend Request message that set up the friendship.

The FriendCounter is the value from the FriendCounter field of the Friend Offer message that set up the friendship.

For Network PDUs that are sent between a Low Power node and Friend node that have a friendship relationship, the friendship security material is used.

For all other Network PDUs, the master security materials are used.

3.8.6.3.2 *Network ID*

The Network ID is derived from the network key such that each network key generates one Network ID. This identifier becomes public information.

$$\text{Network ID} = \text{k3}(\text{NetKey})$$

3.8.6.3.3 *IdentityKey*

The IdentityKey is derived from the network key such that each network key generates one IdentityKey.

$$\text{salt} = \text{s1}(\text{"nkik"})$$

$$P = \text{"id128"} \parallel 0x01$$

$$\text{IdentityKey} = \text{k1}(\text{NetKey}, \text{salt}, P)$$

3.8.6.3.4 *BeaconKey*

The BeaconKey is derived from the network key such that each network key generates one BeaconKey.

$$\text{salt} = \text{s1}(\text{"nkbk"})$$

$$P = \text{"id128"} \parallel 0x01$$

$$\text{BeaconKey} = \text{k1}(\text{NetKey}, \text{salt}, P)$$


3.8.6.4 Global key indexes

Network and application keys are organized within the mesh network into two lists, maintained by a Configuration Client: a list of network keys and a list of application keys. Each list is a shared mesh network resource and can accommodate up to 4096 keys. Keys are referenced using global key indexes: the NetKey Index and the AppKey Index. The key indexes are 12-bit values ranging from 0x000 to 0xFFFF inclusive. A network key at index 0x000 is called the primary NetKey.

3.8.7 Message security

Messages are secured using AES-CCM at two different layers. Messages are encrypted and authenticated at the network layer and at the upper transport layer. Each message is also obfuscated to hide possible identifying information from the packets. This is illustrated in [Figure 3.39](#).

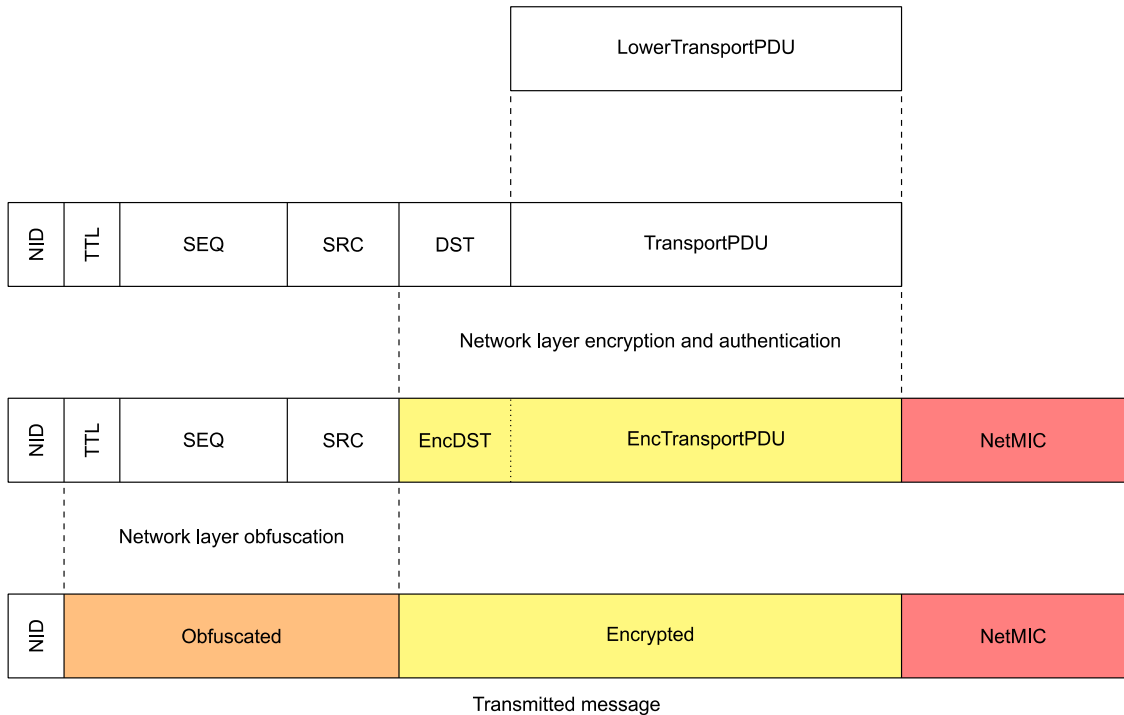


Figure 3.39: Example of network layer encryption, authentication, and obfuscation

Every message has a minimum of 64 bits of authentication information associated with it. This authentication information may be split between the network layer and upper transport layer.

Some messages, known as control messages, are not authenticated at the upper transport layer and therefore have a 64-bit NetMIC. Access messages are authenticated at the upper transport layer and therefore have a 32-bit NetMIC. Access messages that are sent in a single unsegmented message have a 32-bit TransMIC. Access messages that are segmented over multiple Network PDUs can have either a 32-bit or 64-bit TransMIC. This allows a higher layer to determine the level of authentication required to securely deliver the access message and therefore apply the appropriate size for the TransMIC.



3.8.7.1 Upper transport layer authentication and encryption

Authentication and encryption of the access payload is performed by the upper transport layer.

The access payload is encrypted and authenticated using AES-CCM. This is identical to the way that Bluetooth low energy encryption and authentication works. An illustration of the upper transport layer encryption is shown in [Figure 3.40](#).

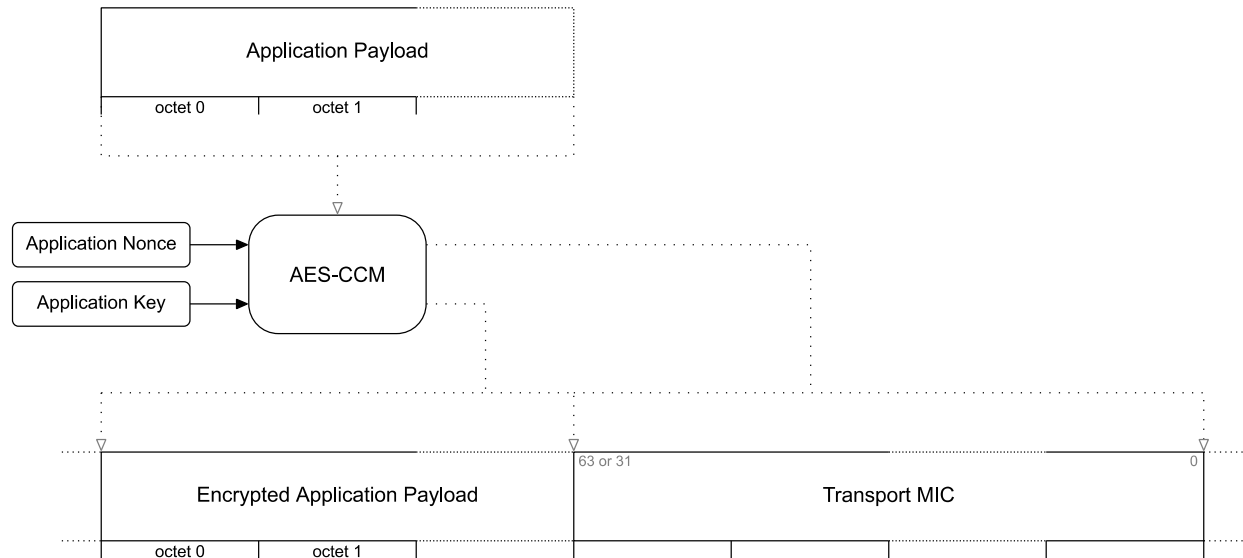


Figure 3.40: Upper Transport layer encryption

If the access payload is secured using the application key, then the access payload is encrypted using the application nonce and the application key.

If the access payload is secured using the device key, then the access payload is encrypted using the device nonce and the device key.

The nonce uses the sequence number and the source address, ensuring that two different nodes cannot use the same nonce. The IV Index is used to provide significantly more nonce values than the sequence number can provide for a given node. Management of the IV Index is described in [Section 3.10.5](#).

Note: The authentication and encryption of the access payload is not dependent on the TTL value, meaning that as the access payload is relayed through a mesh network, the access payload does not need to be re-encrypted at each hop.

When using an application key and the destination address is a virtual address:

$$\text{EncAccessPayload, TransMIC} = \text{AES-CCM} (\text{AppKey}, \text{Application Nonce}, \text{AccessPayload}, \text{Label UUID})$$

When using an application key and the destination address is a unicast address or a group address:

$$\text{EncAccessPayload, TransMIC} = \text{AES-CCM} (\text{AppKey}, \text{Application Nonce}, \text{AccessPayload})$$

When using a device key and the destination address is a unicast address:

$$\text{EncAccessPayload, TransMIC} = \text{AES-CCM} (\text{DevKey}, \text{Device Nonce}, \text{AccessPayload})$$

The concatenation of the encrypted access payload and the transport MIC is called the Upper Transport PDU:

$$\text{Upper Transport PDU} = \text{EncAccessPayload} \parallel \text{TransMIC}$$

3.8.7.2 Network layer authentication and encryption

The destination address and the TransportPDU are encrypted and authenticated using AES-CCM. This is identical to the way that Bluetooth low energy encryption and authentication works.

All Network PDUs are encrypted using an Encryption Key that is derived from a network key (see Section 3.8.6.3.1).

An illustration of the network layer encryption is shown in Figure 3.41.

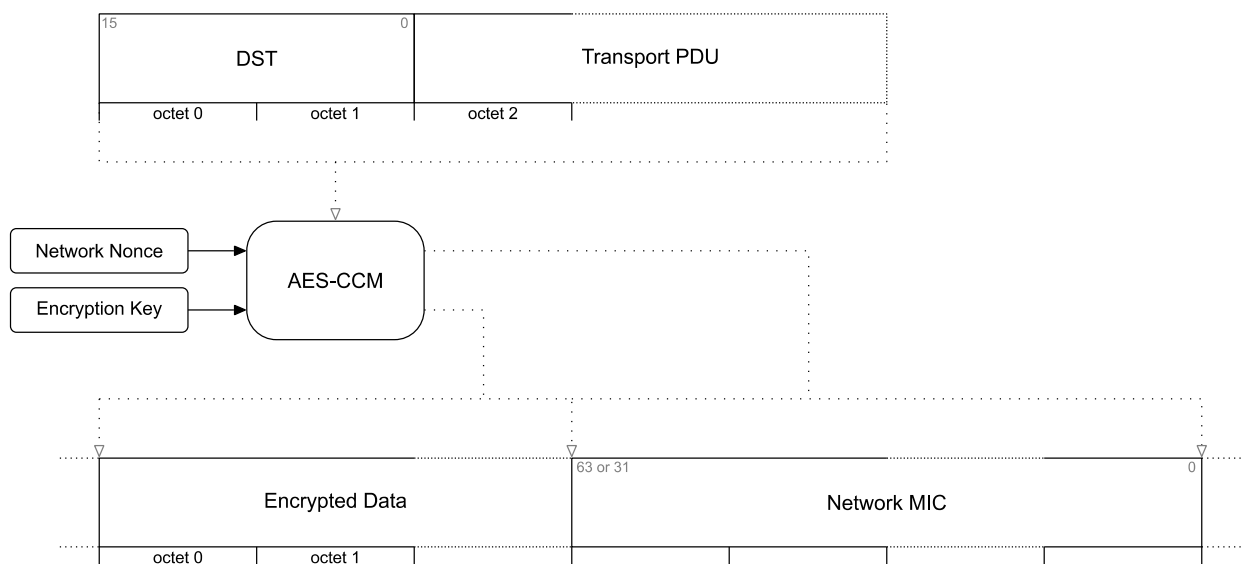


Figure 3.41: Network layer encryption

The following defines how this is performed:

$$\text{EncDST} \parallel \text{EncTransportPDU}, \text{NetMIC} = \text{AES-CCM}(\text{EncryptionKey}, \text{Network Nonce}, \text{DST} \parallel \text{TransportPDU})$$

3.8.7.3 Network layer obfuscation

In order to obfuscate the Network Header (CTL, TTL, SEQ, SRC), these values shall be combined with a result of a single encryption function e , designed to prevent a passive eavesdropper from determining the identity of a node by listening to Network PDUs.

The obfuscation occurs after the application and network message integrity check values have been calculated. The obfuscation is calculated using information available from within the Network PDU. This obfuscation is designed only to help prevent a simple passive eavesdropper from tracking nodes. A determined attacker could still discover patterns within this obfuscation that can lead to the revealing of the source address or sequence number of a node. Critically, obfuscation does not enforce that inputs to the encryption function are unique.

Obfuscation does not protect the Privacy Key from compromise, and given the above design considerations for protection against only passive eavesdroppers, it is considered that the Privacy Key could be compromised with sufficient time. The design of obfuscation includes the IV Index, such that when the IV Index changes, any obfuscation attacks would have to start again.

To obfuscate the Network PDU, the first seven octets of the Network PDU that have already been encrypted are combined with the IV Index and a Privacy Key.

These first seven octets of the Network PDU that have been encrypted include both the EncDST and five octets of either the EncTransportPDU or the EncTransportPDU concatenated with the NetMIC. These octets are known as the PrivacyRandom value.

The Privacy Key is derived using a key derivation function from the network key (see Section 3.8.6.3.1) to protect the network key even if the Privacy Key is compromised.

The IV Index is concatenated with the PrivacyRandom value and used along with the Privacy Key as inputs to the encryption function e . The output of this is known as the PECB value.

The first six octets of the PECB value is then exclusive-ORed with the TTL octet, the sequence number, and the source address fields, and become the ObfuscatedData. The Network PDU is transmitted as the concatenation of the NID/IVI octet, the ObfuscatedData, the EncDST, the EncTransportPDU, and the NetMIC.

An illustration of the network layer obfuscation is shown in [Figure 3.42](#).

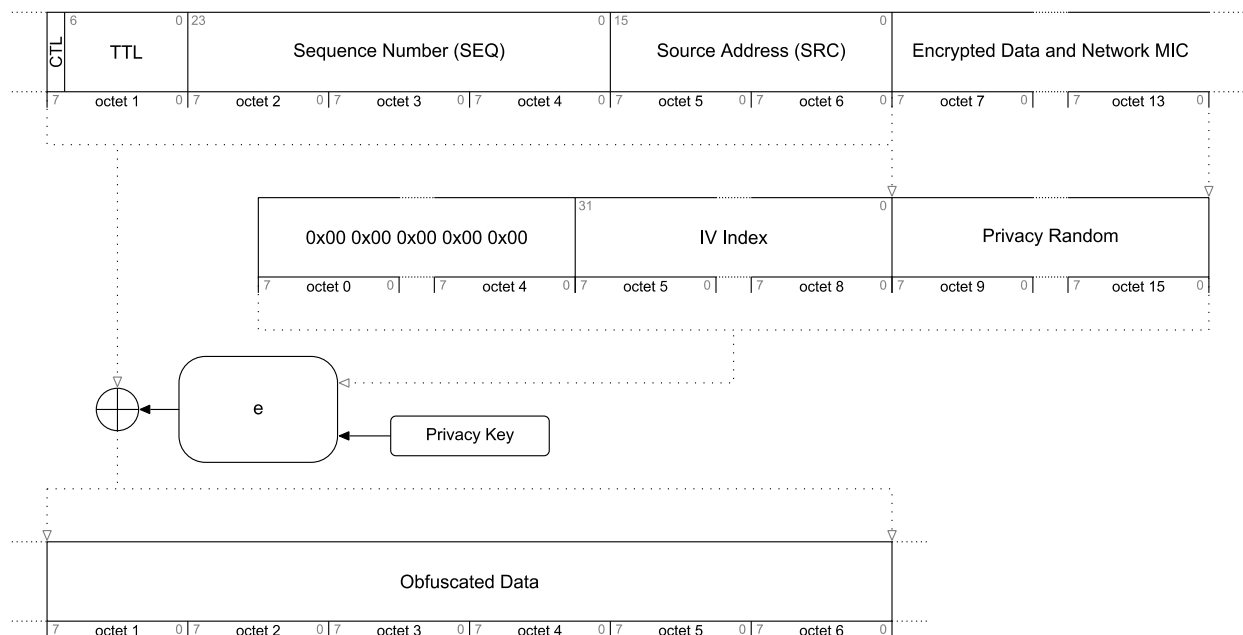


Figure 3.42: Network layer obfuscation

Privacy Random = (EncDST || EncTransportPDU || NetMIC)[0–6]

Privacy Plaintext = 0x0000000000 || IV Index || Privacy Random

PECB = e (PrivacyKey, Privacy Plaintext)

$$\text{ObfuscatedData} = (\text{CTL} \parallel \text{TTL} \parallel \text{SEQ} \parallel \text{SRC}) \oplus \text{PECB}[0-5]$$

When reversing this, the following operations are performed:

$$\text{Privacy Random} = (\text{EncDST} \parallel \text{EncTransportPDU} \parallel \text{NetMIC})[0-6]$$

$$\text{Privacy Plaintext} = 0x0000000000 \parallel \text{IV Index} \parallel \text{Privacy Random}$$

$$\text{PECB} = e(\text{PrivacyKey}, \text{Privacy Plaintext})$$

$$(\text{CTL} \parallel \text{TTL} \parallel \text{SEQ} \parallel \text{SRC}) = \text{ObfuscatedData} \oplus \text{PECB}[0-5]$$

3.8.8 Message replay protection

A message sent by a legitimate originating element can be passively received by an attacker and then replayed later without modification. This is called a replay attack.

Since the originating element has encrypted and authenticated the message using the correct keys, the receiver cannot determine whether it is under a replay attack solely by performing the message integrity checks (i.e., on the Network MIC and, if applicable, on the Transport MIC).

To increase protection against replay attacks, each element increases the sequence number for each new message that it sends. If a valid message has been received from an originating element with a specific sequence number, any future messages from the same originating element that contain numerically lower or equal sequence numbers than the last valid sequence number are very likely replayed messages and shall be discarded. Therefore, messages are delivered to the access layer in sequence number order.

If a lower IV Index from the same originating element has been received, the message shall be discarded.

A node shall implement replay protection for all Access and Control messages that are received from other elements, as well as for Proxy Configuration messages, if applicable.

If a node does not have enough resources to perform replay protection for a given source address, then the node shall discard the message immediately upon reception.

An implementation may perform the replay protection at any layer and in any order with respect to the message authentication steps (the network layer decryption and the transport layer decryption), in order to optimize the message processing flow, the number of cryptographic operations or the memory usage.

However, the implementation shall follow the fundamental requirement that it shall either be able to determine if a certain message is being replayed, or it shall discard the message immediately upon reception.

Figure 3.43 illustrates an example of a replay protection list implementation that handles a multi-segment message transaction which is under a replay attack. The sequence number of the last segment that has been received for this message is stored for that peer node in the replay protection list.

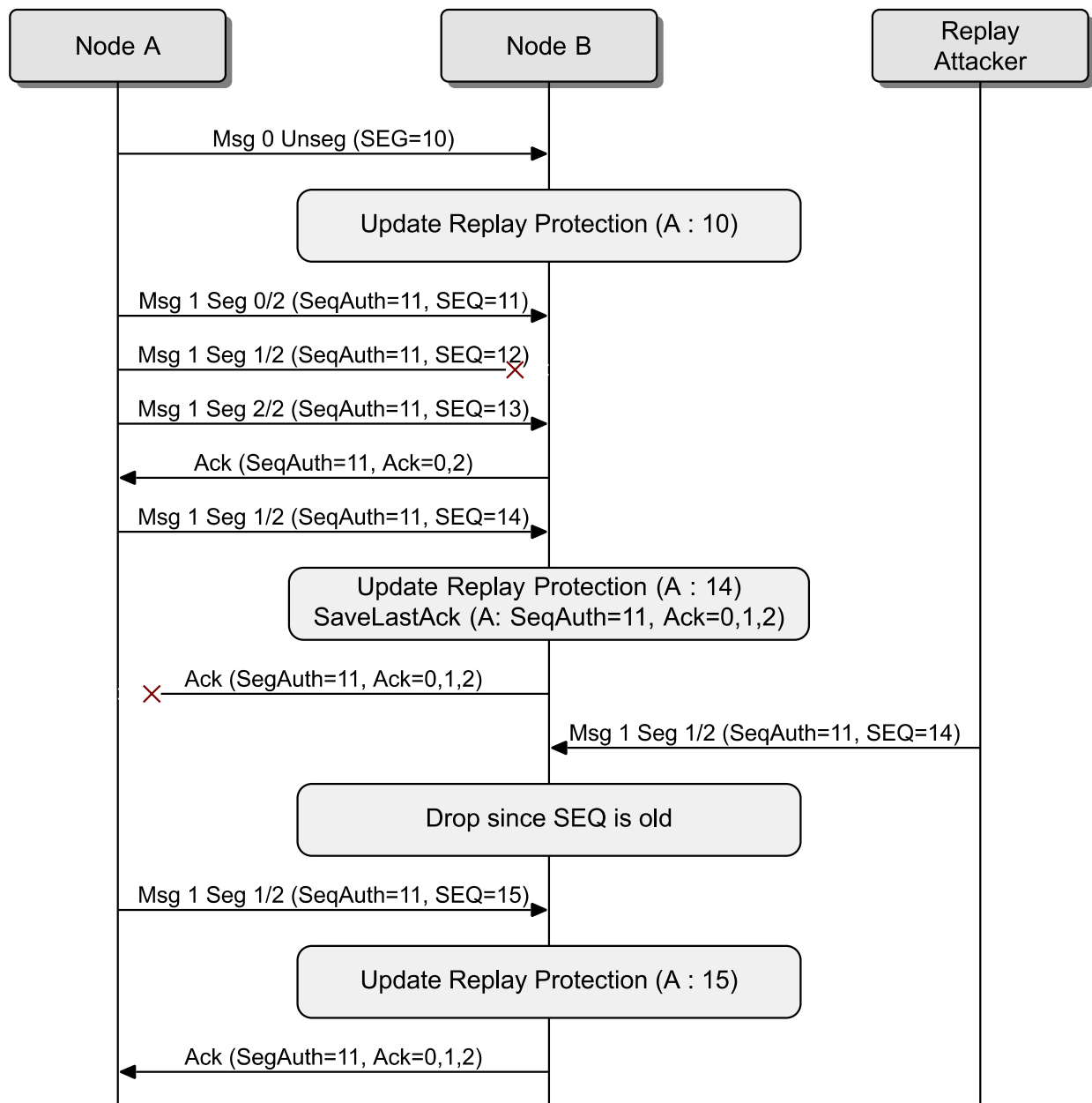


Figure 3.43: Example of updating replay protection list for segmented messages

3.9 Mesh beacons

Mesh beacons are packets advertised periodically by nodes and unprovisioned devices.

Mesh beacons are contained in a «Mesh Beacon» AD Type. The first octet of the Mesh Beacon advertising data payload (Beacon Type field) determines the type of beacon. Mesh beacons are forwarded to other bearers using the Proxy protocol (see Section 6).

The format of the Mesh Beacon AD Type is shown in Figure 3.44.

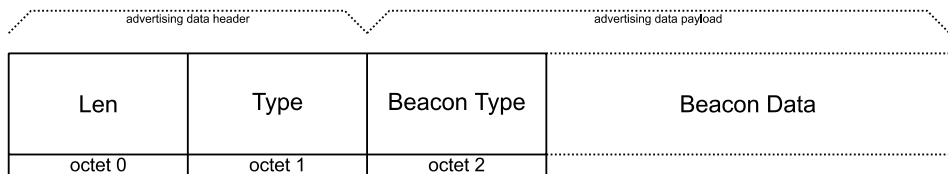


Figure 3.44: Mesh Beacon AD Type format

The Beacon Type values are defined in [Table 3.52](#).

Value	Definition
0x00	Unprovisioned Device beacon
0x01	Secure Network beacon
0x02–0xFF	Reserved for Future Use

Table 3.52: Beacon Type values

Mesh beacons shall be advertised with non-connectable and non-scannable undirected advertising events.

3.9.1 Endianness

All multiple-octet numeric values in mesh beacons shall be sent in “big endian”, as described in Section [3.1.1.1](#).

3.9.2 Unprovisioned Device beacon

The Unprovisioned Device beacon is used by devices that are unprovisioned to allow them to be discovered by a Provisioner.

The format of this beacon is illustrated in [Figure 3.45](#) and defined in [Table 3.53](#).

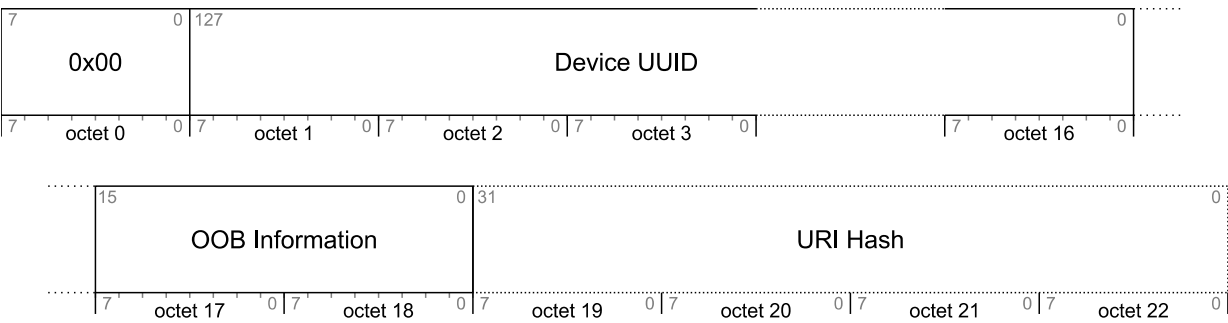


Figure 3.45: Unprovisioned device beacon format

Field	Size (octets)	Notes
Beacon Type	1	Unprovisioned Device beacon type (0x00)
Device UUID	16	Device UUID uniquely identifying this device (see Section 3.10.3)



Field	Size (octets)	Notes
OOB Information	2	See Table 3.54
URI Hash	4	Hash of the associated URI advertised with the URI AD Type (optional field)

Table 3.53: Unprovisioned Device beacon format

The OOB Information field shown in [Table 3.54](#) is used to help drive the provisioning process by indicating the availability of OOB data, such as a public key of the device.

Bit	Description
0	Other
1	Electronic / URI
2	2D machine-readable code
3	Bar code
4	Near Field Communication (NFC)
5	Number
6	String
7	Reserved for Future Use
8	Reserved for Future Use
9	Reserved for Future Use
10	Reserved for Future Use
11	On box
12	Inside box
13	On piece of paper
14	Inside manual
15	On device

Table 3.54: OOB Information field

Along with the Unprovisioned Device beacon, the device may also advertise a separate non-connectable advertising packet with a Uniform Resource Identifier (URI) data type (as defined in [\[7\]](#)) that points to out-of-band (OOB) information such as a public key. To allow the association of the advertised URI with the Unprovisioned Device beacon, the beacon may contain an optional 4-octet URI Hash field.

The value of the URI Hash field is calculated using the following formula:

$$\text{URI Hash} = \text{s1}(\text{URI Data})[0-3]$$

The URI Data is a buffer containing the Uniform Resource Identifier (URI) data type, as defined in [\[7\]](#).



3.9.3 Secure Network beacon

The Secure Network beacon is used by nodes to identify the subnet and its security state.

The format of this beacon is illustrated in [Figure 3.46](#) and defined in [Table 3.55](#).

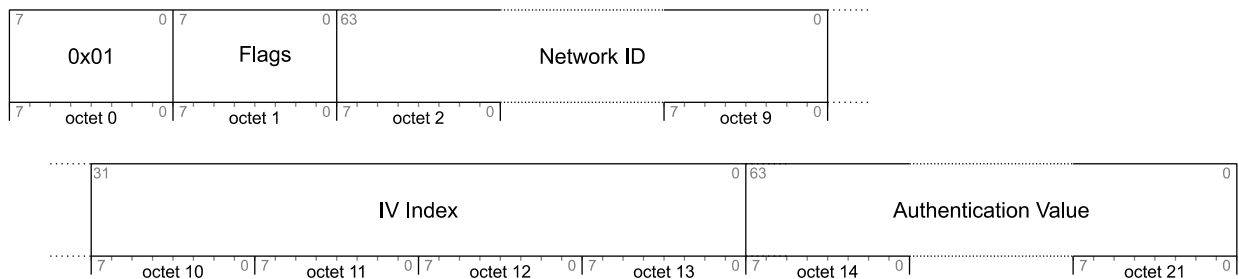


Figure 3.46: Secure Network beacon

Field	Size (octets)	Notes
Beacon Type	1	Secure Network beacon (0x01)
Flags	1	Contains the Key Refresh Flag and IV Update Flag
Network ID	8	Contains the value of the Network ID
IV Index	4	Contains the current IV Index
Authentication Value	8	Authenticates security network beacon

Table 3.55: Secure Network beacon format

The Flags field is defined in [Table 3.56](#) as:

Bits	Definition
0	Key Refresh Flag 0: False 1: True
1	IV Update Flag 0: Normal operation 1: IV Update active
2–7	Reserved for Future Use

Table 3.56: Flags field definition

The Network ID field contains the Network ID of this network.

The IV Index field contains the current IV Index of this mesh network.



The Authentication Value field is computed as defined below:

$$\text{Authentication Value} = \text{AES-CMAC}_{\text{BeaconKey}} (\text{Flags} \parallel \text{Network ID} \parallel \text{IV Index}) [0-7]$$

The generation of the Secure Network beacon is illustrated in [Figure 3.47](#).

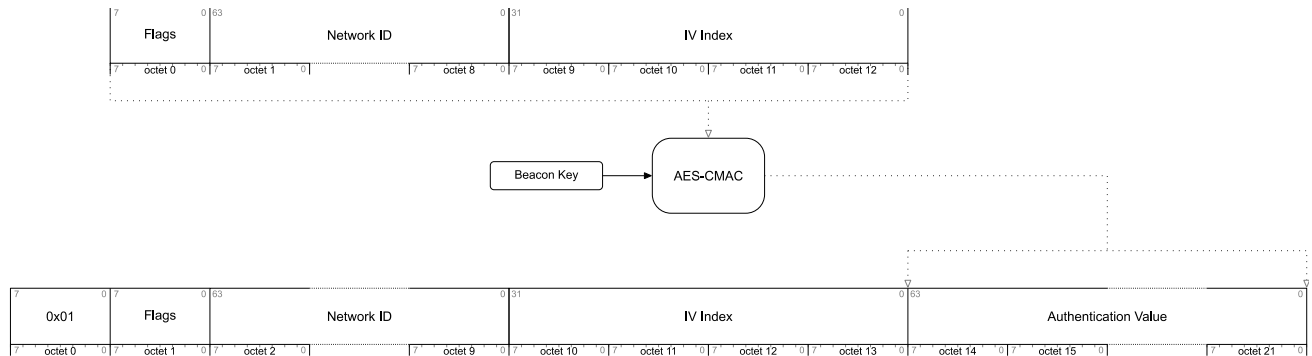


Figure 3.47: Secure Network beacon generation

3.9.3.1 Secure Network beacon behavior

When a Secure Network beacon is received on a known subnet and authenticated, the node shall monitor for IV Index updates (see Section 3.10.5) and Key Refresh procedures (see Section 3.10.4). To authenticate a Secure Network beacon, a node calculates the Authentication Value as defined in Section 3.9.3 and checks if it is equal to the Authentication Value field in the received Secure Network beacon.

A Secure Network beacon may be sent for each subnet that a node is a member of to identify the subnet and inform about IV Index updates (see Section 3.10.5) and Key Refresh procedures (see Section 3.10.4).

Relay and Friend nodes should send beacons and other nodes may send beacons. The time between sending two consecutive beacons is called the Beacon Interval. An implementation may define the Beacon Interval together with a back-off procedure to prevent other nodes from overloading the network with too many beacons. The expected behavior is that each node receives one beacon for a given subnet approximately every 10 seconds.

For each subnet, to determine the Beacon Interval, the node should continuously observe beacons and keep a rolling count of the number of beacons for the subnet over a given observation period. The Beacon Interval should be determined using the formula below:

$$\text{Beacon Interval} = \text{Observation Period} * (\text{Observed Number of Beacons} + 1) / \text{Expected Number of Beacons}$$

If the computed Beacon Interval is less than 10 seconds, it should be set to 10 seconds. If the computed Beacon Interval is greater than 600 seconds, it should be set to 600 seconds.

The Observation Period in seconds should typically be double the typical Beacon Interval. Each of the subnets has a separate Secure Network beacon, and therefore, the Expected Number of Beacons, Observed Number of Beacons, and Observation Period may be different for each subnet.

The Observed Number of Beacons is the number of beacons observed for this subnet over the Observation Period.

The Expected Number of Beacons is the Observation Period divided by 10 seconds.

3.10 Mesh network management

3.10.1 Mesh Network Creation procedure

To create a mesh network, a Provisioner is required. A Provisioner shall generate a network key, provide an IV Index, and allocate a unicast address.

The network key shall be generated using a random number generator, which shall be compatible with the requirements in Volume 2, Part H, Section 2 of the Core Specification [1].

The IV Index shall be set to 0x00000000.

The unicast address shall be set to a unicast address that is allocated by the Provisioner.

The mesh network is created using the above information. The Provisioner's primary element shall be assigned the unicast address. The Provisioner's other elements shall be allocated the sequential addresses after the unicast address.

The Provisioner can then find unprovisioned devices by scanning for Unprovisioned Device beacons using active or passive scanning. The Provisioner can then provision these devices to become nodes within the mesh network. Once these nodes have been provisioned, the Configuration Client can then configure the nodes by providing them application keys and setting publish and subscribe addresses so that the nodes can communicate with each other.

Note: The Provisioner's device key is only used when one Provisioner is communicating directly with another Provisioner and this device key has been communicated OOB. Device keys of Provisioners should be coordinated across multiple Provisioners.

3.10.2 Temporary guest access

It is possible to provide a node with temporary guest access to a mesh network. This is done by creating a separate guest subnet by providing a separate network key to the guest and to the nodes the guest will have access to.

Separate application keys are also provided to the guest to restrict the models that the guest has access to at the access layer.

The guest never obtains application keys or network keys used by nodes and models that are excluded from guest access. Only nodes that belong to the guest subnet will communicate with the guest node; within these nodes, only models bound to the guest application keys can be used by the guest. This allows guest access to be very finely controlled down to specific nodes and functionalities.

Guests cannot initiate IV Index updates on the primary subnet. This protects the IV Index, which is a network shared resource, from a potentially malicious behavior.

Guest access is configured by a Configuration Client using the Configuration Server model that is secured by device keys. Multiple guests may be provided with guest access, each within their own guest subnet and model domain.



Guest access is revoked by refreshing application and network keys through the Key Refresh procedure (see Section 3.10.4).

3.10.3 Device UUID

To decrease the complexity of deploying nodes, a unique Bluetooth BD_ADDR is not required for mesh operations. Instead, each node shall be assigned a 128-bit UUID known as the Device UUID. Device manufacturers shall follow the standard UUID format as defined in [8] and generation procedure to ensure the uniqueness of each Device UUID.

3.10.4 Key Refresh procedure

This procedure is used when the security of one or more network keys and/or one or more of the application keys has been compromised or could be compromised.

For example, when a node is removed from the network, all remaining nodes would have their keys changed such that the removed node would not have knowledge of the new security credentials being used if that node was compromised after being disposed. This is known as the "trash-can attack."

The procedure allows the blacklisting of some nodes (i.e., not sharing the new key(s) with some nodes that are considered compromised or a security risk) because the distribution of the new key(s) is based on device keys established during provisioning between a Configuration Client and each node.

The procedure consists of changing the network keys, the application keys, and all the derived credentials, with a minimal disruption to the operation of the network.

Each key index within a node holds either one or two keys. If two keys are being held, then the most recently added key is referred to as the new key and the other key is referred to as the old key.

The Key Refresh procedure manages the process of changing from one key to another key for a NetKey and its associated AppKeys. AppKeys that have not been given a new key value shall not be changed when their associated NetKey is updated.

The Key Refresh procedure is independent of the IV Update procedure. Both procedures can be performed at the same time, interleaved, or at different times. The behavior of the IV Update procedure has no impact on the Key Refresh procedure, and the Key Refresh procedure has no impact on the IV Update procedure.

The Key Refresh procedure uses three phases to move a network from the current state, using only old keys, to the new state, using only new keys, as illustrated in Figure 3.48:

- The first phase involves distributing new keys to each node. The nodes will continue to transmit using the old keys but can receive using the old keys and new keys.
- The second phase involves transmitting a Secure Network beacon that signals to the network that all nodes have the new keys. The nodes will then transmit using the new keys but can receive using the old keys and the new keys.
- The third phase involves transmitting another Secure Network beacon that signals to the network that all nodes should revoke the old keys. The nodes will transmit and receive using only the new keys.



It is possible to update each NetKey independently of all other NetKeys. A Key Refresh procedure for one NetKey can be in a different phase to another Key Refresh procedure for other NetKeys.

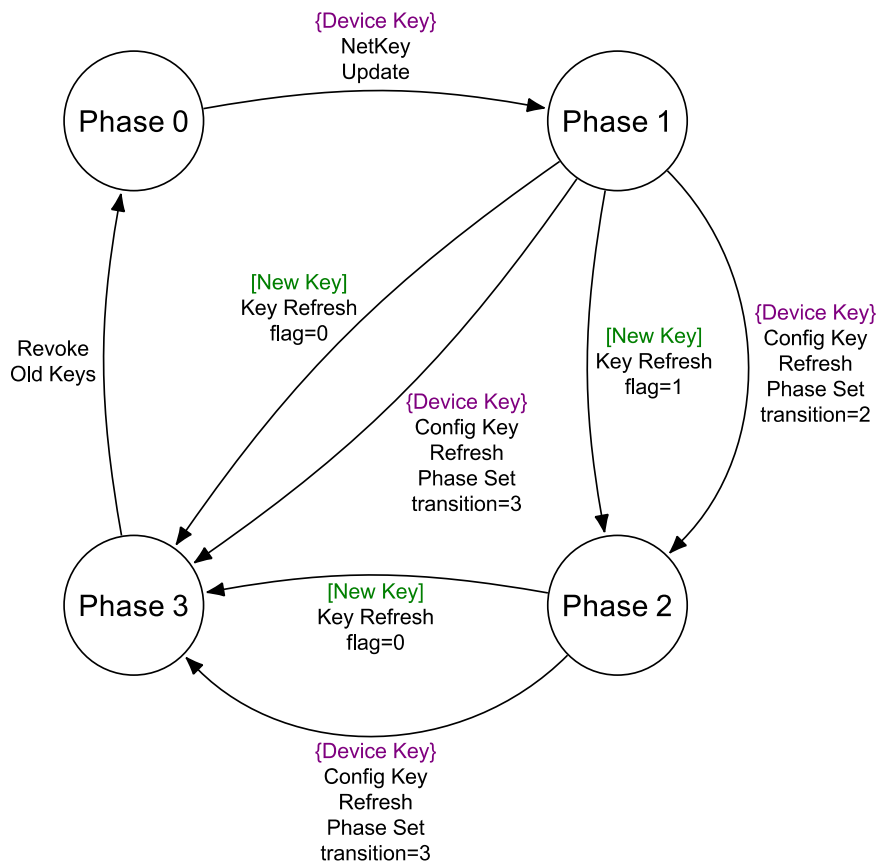


Figure 3.48: Key Refresh diagram

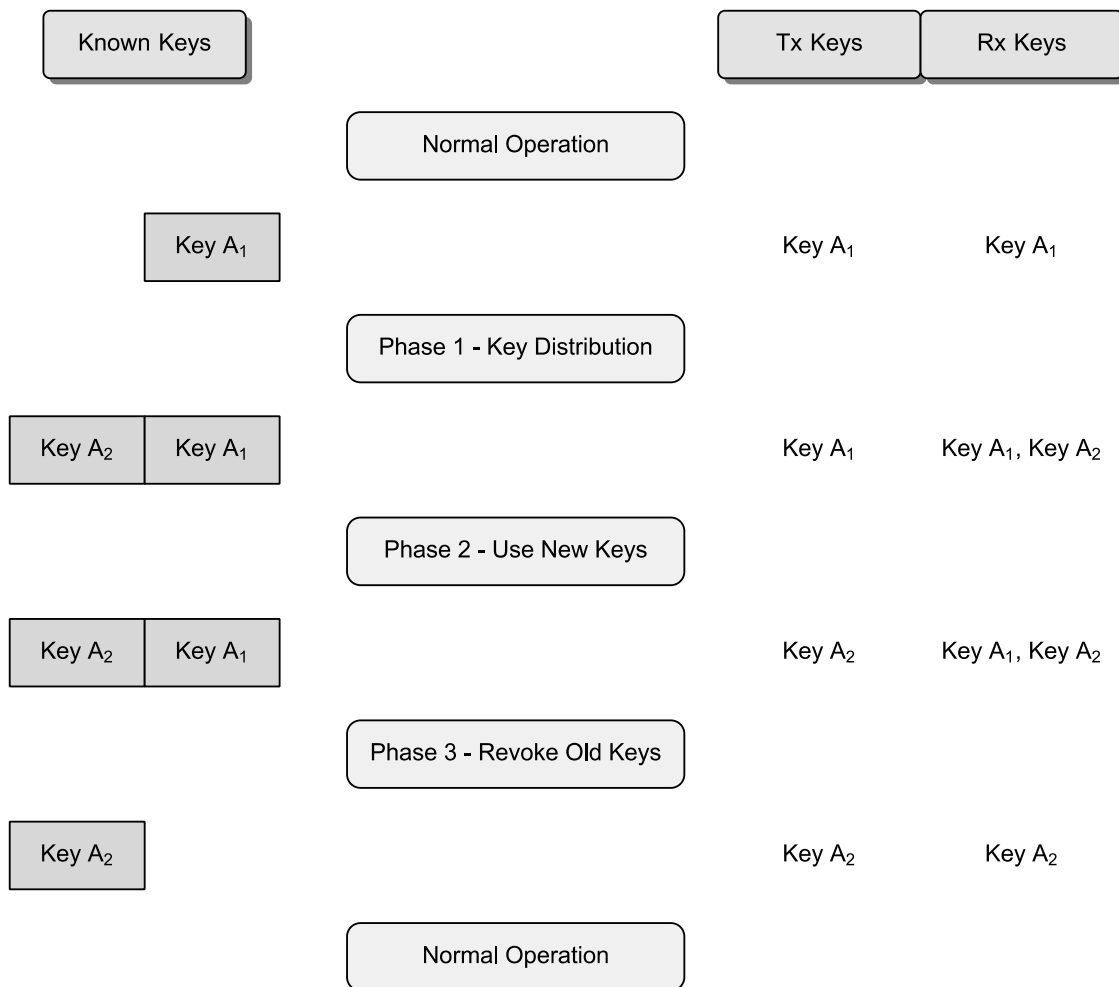


Figure 3.49: Key Refresh procedure overview

As illustrated in [Figure 3.49](#), nodes in normal operation only know a single key, Key A₁. This key is used for transmitting and receiving packets. When Phase 1 (Key Distribution) is performed, each node will receive a new key that is stored in the same key index. The nodes will continue to transmit using the old key, Key A₁, but will additionally receive using the new key, Key A₂. Once all nodes have been informed of the new key, Phase 2 (Use New Keys) can start. This sends a signal around the network that the new key should now be used. The nodes will therefore start to transmit using the new key, Key A₂, but will also receive from the old and new keys. Finally, Phase 3 (Revoke Old Keys) will revoke the old keys meaning that nodes will only transmit and receive using a single key, Key A₂. After the old keys have been revoked, the nodes are back to normal operation.

To increase robustness of the Key Refresh procedure, the node shall successfully process a Config NetKey Update message on a valid NetKeyIndex when the NetKey value is different and the Key Refresh procedure has not been started, or when the NetKey value is the same in Phase 1. The Config NetKey Update message shall generate an error when the node is in Phase 2 or Phase 3. The Config AppKey Update message shall generate an error when node is in normal operation, Phase 2, or Phase 3 or in Phase 1 when the Config AppKey Update message on a valid AppKeyIndex when the AppKey value is different.

3.10.4.1 Phase 1 – distribution of the new keys

The procedure is triggered by a Configuration Client. A Configuration Client shall determine the set of nodes that will receive the new NetKey and the new AppKeys bound to it. Any node not receiving the new keys is blacklisted (i.e., they will effectively be removed from the network in Phase 3).

The Configuration Client shall send the new keys to each node that is not blacklisted. New keys are distributed using the Config NetKey Update message and the Config AppKey Update message, see Sections 4.3.2.32 and 4.3.2.38.

Upon receiving the new keys, the node shall store them. During this phase, the node shall transmit using the old keys and receive using both the old keys and the new keys.

The Configuration Client should be aware that Low Power nodes may have a very high latency, and therefore new keys may take additional time to be delivered to those nodes. On receiving Segment Acknowledgments with the OBO field set to 1 to key update messages sent to a Low Power node, a Configuration Client may perform a PollTimeout List procedure to the Low Power node's Friend node (identifying the Friend node using the value of SRC field of the Segment Acknowledgment) in order to obtain the current value of the PollTimeout timer, and schedule retries of NetKey or AppKey updates based on this value.

Upon receiving a Secure Network beacon with the Key Refresh flag set to 0 using the new NetKey in Phase 1, the node shall immediately transition to Phase 3, which effectively skips Phase 2.

When a Configuration Client determines that all nodes that are not blacklisted have received the new keys, Phase 1 is complete and it shall transition to Phase 2.

Note: The Mesh Proxy Service advertising depends on the NetKey value and must be updated upon transition from Phase 1 when applicable.

3.10.4.2 Phase 2 – switching to the new keys

The Configuration Client shall either start sending a Secure Network beacon with the Key Refresh flag set to 1, secured using the new NetKey, see Section 3.9.3, or initiate the Key Refresh Phase transition by sending a Config Key Refresh Phase Set message with the Transition parameter set to 0x02 to one or more nodes.

A Relay node or Friend node, when it is in Phase 2 for a given NetKey, shall send Secure Network beacons for the new NetKey with the Key Refresh flag set to 1 and it shall stop sending Secure Network beacons for the old NetKey.

Upon receiving a Secure Network beacon or a Friend Update message with the Key Refresh flag set to 1, or a Config Key Refresh Phase Set message with the Phase parameter set to 0x02, the node shall set the Key Refresh Phase for this NetKey to Phase 2. When in Phase 2, the node shall only transmit messages and Secure Network beacons using the new keys, shall receive messages using the old keys and the new keys, and shall only receive Secure Network beacons secured using the new NetKey.

The Configuration Client should be aware that Low Power nodes may have a very high latency, and therefore Low Power nodes may take additional time to receive the Key Refresh flag information from a Friend node.



When a Configuration Client determines that all nodes that are not blacklisted are in Phase 2, Phase 2 is complete and it shall transition to Phase 3.

3.10.4.3 Phase 3 – revoking old keys

The Configuration Client shall either start sending a Secure Network beacon with the Key Refresh flag set to 0, secured using the new NetKey (see Section 3.9.3), or initiate Key Refresh Phase transition by sending a Config Key Refresh Phase Set message with the Transition parameter set to 0x03 to on one or more nodes. The Configuration Client shall revoke the old keys.

Note: When a device has been recently provisioned and does not have the old keys, it will not know the old keys and therefore will not be able to revoke the old keys.

A Relay node or Friend node, when it is in Phase 3 for a given NetKey, shall send Secure Network beacons for the new NetKey with the Key Refresh flag set to 0.

Upon receiving a Secure Network beacon or a Friend Update message with the Key Refresh flag set to 0 or a Config Key Refresh Phase Set message with the Transition parameter set to 0x03, the node shall revoke the old keys and shall send Secure Network beacons for the new NetKey with the Key Refresh flag set to 0. The node will only transmit and receive using the new keys. It shall ignore Secure Network beacons and Friend Update messages secured using the new NetKey with the Key Refresh flag set to 1. After old keys are revoked, the Key Refresh state will be 0.

The Configuration Client should be aware that Low Power nodes may have a very high latency, and therefore Low Power nodes may take additional time to receive the Key Refresh flag information from a Friend node.

3.10.5 IV Update procedure

The IV Index provides entropy for the nonce used for the authenticated encryption (AES-CCM) in both the application and network layers. Therefore, it must be changed often enough to avoid repeated use of sequence numbers in the nonce. The IV Update procedure is initiated by any node that is a member of a primary subnet. This may be done when the node believes it is at risk of exhausting its sequence numbers, or it determines another node is close to exhausting its sequence numbers. The node changes its IV Index and sends an indication to other nodes in the mesh that the IV Index is being updated. This is then followed by a change back to normal operation by the same or some other node in the mesh.

At least one node with the Secure Network Beacon state set to 1, on a connected subnet with a key index different from 0x000, must also be on the primary subnet.

Note: Nodes that rarely send messages will rarely initiate the IV Update procedure.

The IV Update procedure defines two states of operation:

- Normal Operation – IV Update Flag = 0
- IV Update in Progress – IV Update Flag = 1

During the Normal Operation state, the IV Update Flag in the Secure Network beacon and in the Friend Update message shall be set to 0. When this state is active, a node shall transmit using the current IV Index and shall process messages from the current IV Index and also the current IV Index - 1.



For example, when IV Update Flag is set to 0, and the current IV Index is equal to 0x00101847, then the node shall transmit using the IV Index 0x00101847 and accept messages received using the IV Index 0x00101847 when the IVI field in the network layer is set to 1, and 0x00101846 when the IVI field in the network layer is set to 0.

If a node in Normal Operation receives a Secure Network beacon with an IV index greater than the last known IV Index + 1, it may initiate an IV Index Recovery procedure, see Section 3.10.6.

If a node in Normal Operation receives a Secure Network beacon with an IV index equal to the last known IV index+1 and the IV Update Flag set to 0, the node may update its IV without going to the IV Update in Progress state, or it may initiate an IV Index Recovery procedure (Section 3.10.6), or it may ignore the Secure Network beacon. The node makes the choice depending on the time since last IV update and the likelihood that the node has missed the Secure Network beacons with the IV update Flag set to 1.

If a node in Normal Operation receives a Secure Network beacon with an IV index less than the last known IV Index or greater than the last known IV Index + 42, the Secure Network beacon shall be ignored.

Note: This above requirement allows a node to be away from the network for 48 weeks. A node that is away from a network for longer than 48 weeks must be reprovisioned.

If this node is a member of a primary subnet and receives a Secure Network beacon on a secondary subnet with an IV Index greater than the last known IV Index of the primary subnet, the Secure Network beacon shall be ignored.

A node shall not start an IV Update procedure more often than once every 192 hours.

After 96 hours of operating in Normal Operation, a node may initiate the IV Update procedure by transitioning to the IV Update in Progress state. When a node transitions from the Normal Operation state to the IV Update in Progress state, the IV Index on the node shall be incremented by one.

The transition from Normal Operation state to IV Update in Progress state must occur at least 96 hours before the sequence numbers are exhausted, as defined in Section 3.8.3.

A node that is in Normal Operation state that receives and accepts a Secure Network beacon with the IV Update Flag set to 1 (indicating the IV Update in Progress state) should transition to the IV Update in Progress state as soon as possible.

During the IV Update in Progress state, the IV Update Flag in the Secure Network beacon and in the Friend Update message shall be set to 1. When this state is active, a node shall transmit using the current IV Index - 1 and shall process messages from the current IV Index - 1 and also the current IV Index.

For example, if the IV Index was 0x00101847 before transitioning from the Normal Operation state to the IV Update in Progress state, after transitioning, the IV Update Flag will be 1, the current IV Index will be 0x00101848, and the node shall transmit using the IV Index 0x00101847 and accept messages received using the IV Index 0x00101847 when the IVI field in the network layer is set to 1 and 0x00101848 when the IVI field in the network layer is set to 0. This allows all nodes that are in the Normal Operation state using the old IV Index to send messages to this node, and this node sends messages to those nodes that have not yet transitioned.



After at least 96 hours and before 144 hours of operating in IV Update in Progress state, the node shall transition back to the IV Normal Operation state and not change the IV Index. At the point of transition, the node shall reset the sequence number to 0x000000.

For example, when transitioning back to the Normal Operation state, the IV Update Flag will be 0, the current IV Index will be 0x00101848, the node shall transmit using the IV Index 0x00101848 and accept messages received using the IV Index 0x00101847 when the IVI field in the network layer is set to 1 and 0x00101848 when the IVI field in the network layer is set to 0. This allows the node to send messages to all nodes in the network whether they are also in the Normal Operation state or in the IV Update in Progress state. It also allows the node to receive messages from all nodes that are in the Normal Operation state or the IV Update in Progress state. A summary of the IV Update procedure is provided in [Table 3.57](#) below.

IV Index	IV Update Flag	IV Update Procedure State	IV Index Accepted	IV Index used when transmitting
n	0	Normal	n-1, n	n
m (m=n+1)	1	In Progress	m-1, m	m-1
m	0	Normal	m-1, m	m

Table 3.57: IV Update procedure summary

A node that is in the IV Update in Progress state that receives and accepts a Secure Network beacon with the IV Update Flag set to 0 (indicating the Normal Operation state) should transition into the Normal Operation state as soon as possible.

A node shall defer state change from IV Update in Progress to Normal Operation, as defined by this procedure, when the node has transmitted a Segmented Access message or a Segmented Control message without receiving the corresponding Segment Acknowledgment messages. The deferred change of the state shall be executed when the appropriate Segment Acknowledgment message is received or timeout for the delivery of this message is reached.

Note: This requirement is necessary because upon completing the IV Update procedure the sequence number is reset to 0x000000 and the SeqAuth value would not be valid.

When a node is added to a network, the node is given an IV Index. If the node is added to a network when the network is in Normal operation, then it shall operate in Normal operation for at least 96 hours. If a node is added to a network while the network is in the IV Update in Progress state, then the node shall be given the new IV Index value and operate in Normal operation for at least 96 hours.

3.10.5.1 IV Update test mode

To enable efficient testing of the IV Update procedure, a node shall support IV Update test mode used testing in connection with the Bluetooth Qualification Process. The activation of the test mode shall be carried out locally (via a HW or SW interface). The IV Update test mode only removes the 96-hour limit; all other behavior of the device shall be unchanged.

Two signals are defined in the IV Update test mode:

- Transit to IV Update in Progress signal
- Transit to Normal signal

When the Transit to IV Update in Progress signal is received, the node shall transition to the IV Update in Progress state, ignoring the 96 hour limit.

When the Transit to Normal signal is received, the node shall transition to the Normal state, ignoring the 96 hour limit.

3.10.6 IV Index Recovery procedure

A node shall support the IV index recovery procedure because a node that is away from the network for a long time may miss IV Update procedures, in which case it can no longer communicate with the other nodes. In order to recover the IV Index, the node must listen for a Secure Network beacon, which contains the Network ID and the current IV Index. Upon receiving and successfully authenticating a Secure Network beacon for a primary subnet whose IV Index is 1 or more higher than the current known IV Index, the node shall set its current IV Index and its current IV Update procedure state from the values in this Secure Network beacon.

Note: After the IV Index Recovery procedure has updated the IV Index, the 96 hour time limits for changing the IV Update procedure state, as defined in the IV Update procedure, do not apply.

Given that nodes collectively transmit a Secure Network beacon once every 10 seconds, a low duty cycle node will have to listen for an average of 5 seconds to recover the current IV Index before transmitting and receiving mesh messages. If a Low Power node has insufficient power to listen for 5 seconds, then it must stay up to date with the current IV Index by polling its Friend node at least once every 96 hours.

The node shall not execute more than one IV Index Recovery within a period of 192 hours.

3.10.7 Node Removal procedure

In some cases, it may be necessary to remove a node from a network (e.g., for security reasons or due to the hardware and/or software failure of the node).

Node removal is a consequence of blacklisting the node by excluding it from the Key Refresh procedure (see Section 3.10.4).

After a node is removed from a network, its unicast addresses may be reused by a Provisioner. A Provisioner shall only reuse these addresses after the current IV Index (at the time of removal) has been updated (see Section 3.10.5) in order to enable the SEQ numbers to be reused.



3.11 Message processing flow

The flow of messages through the layers defined by this specification, along with key decision points, is illustrated by [Figure 3.51](#) (lower layers) and [Figure 3.50](#) (upper layers).

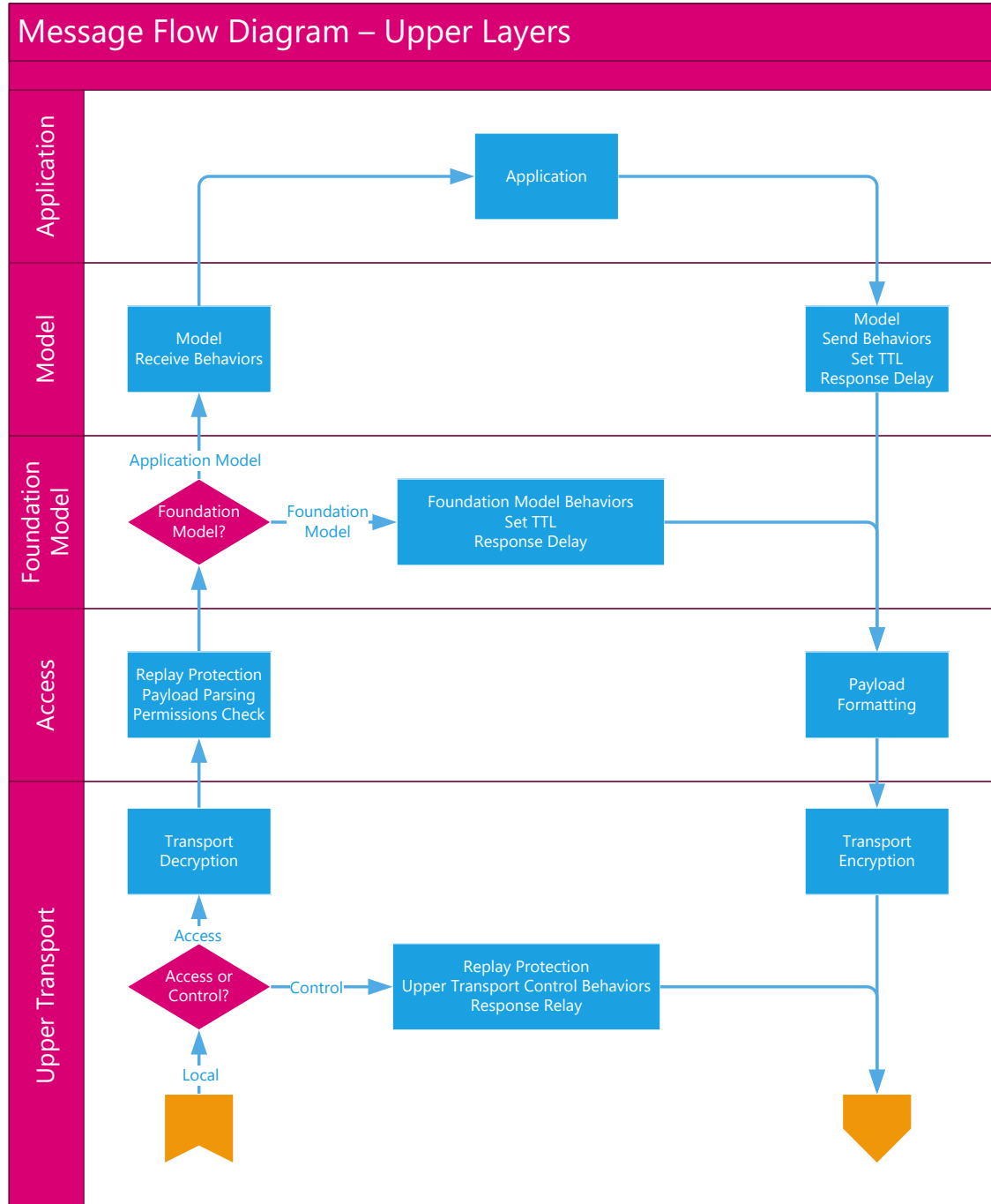


Figure 3.50: Message flow diagram – upper layers

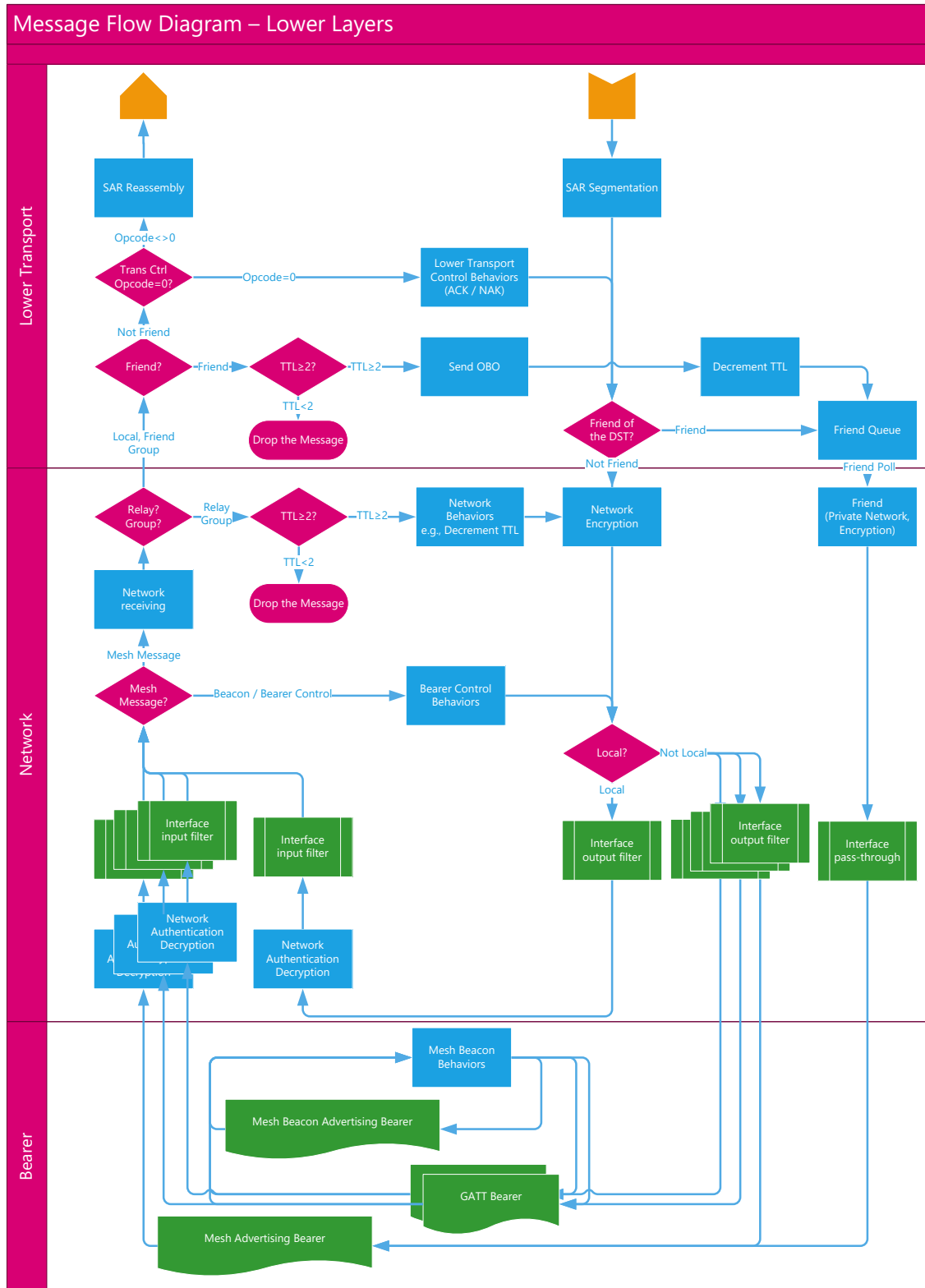


Figure 3.51: Message flow diagram – lower layers

The flow of messages through the access layer defined by this specification, along with key decision points, is illustrated by [Figure 3.52](#).

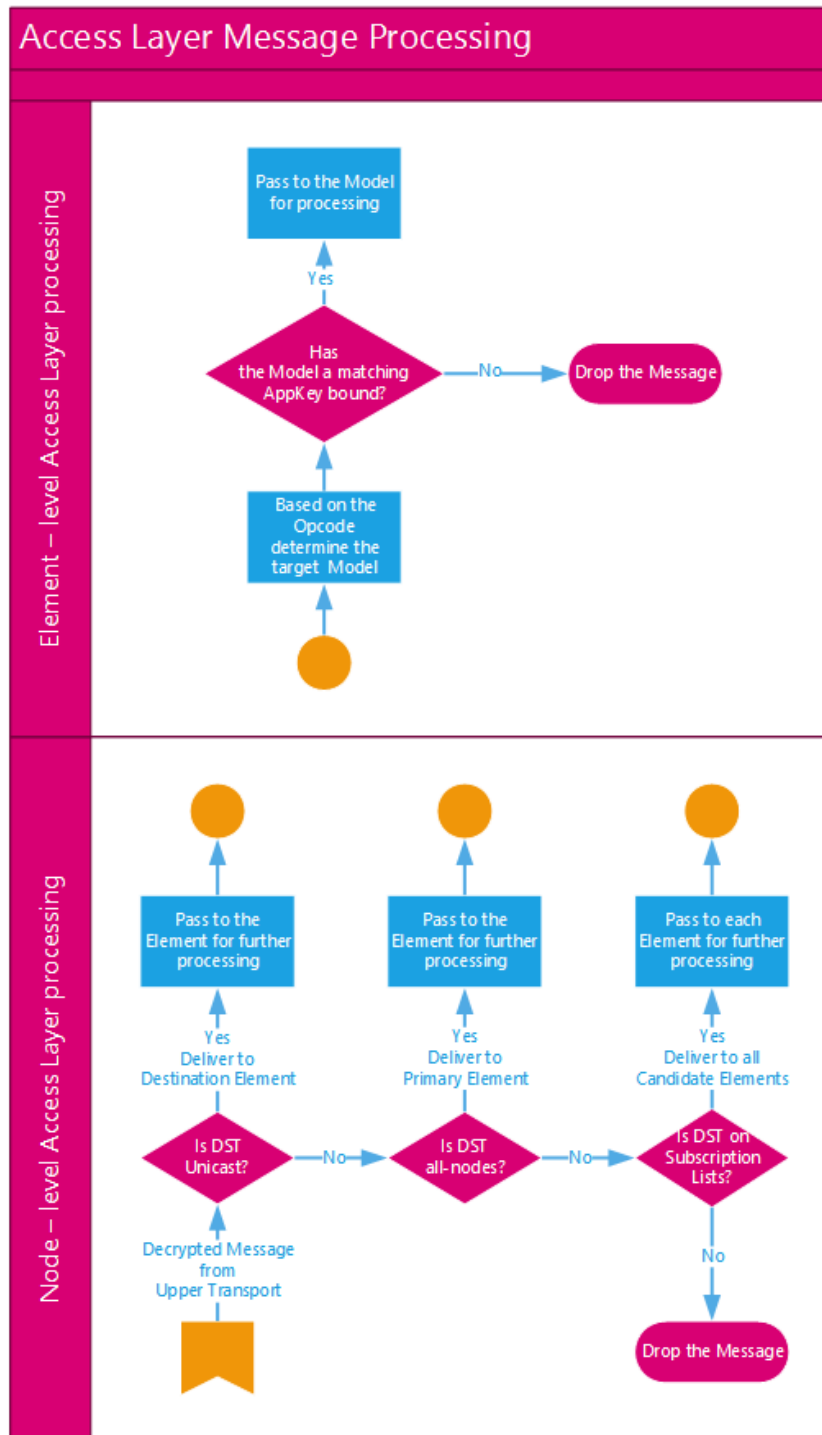


Figure 3.52: Message flow diagram – access layer

4 Foundation models

The Foundation Models define the access layer states, messages, and models required to configure and manage a mesh network.

4.1 Conventions

4.1.1 Endianness

All multiple-octet numeric values in this layer shall be “little endian”, as described in Section 3.1.1.2.

4.1.2 Log field transformation

In order to compress two-octet values into one-octet fields, the following logarithmic transformation is used: any two-octet value is mapped onto a one-octet field value representing the largest integer n , where $2^{(n-1)}$ is less than or equal to the two-octet value.

This transformation is represented in Table 4.1.

Log Field Value	2-octet Value
0x01	0x0001
0x02	0x0002 through 0x0003
0x03	0x0004 through 0x0007
0x04	0x0008 through 0x000F
0x05	0x0010 through 0x001F
0x06	0x0020 through 0x003F
0x07	0x0040 through 0x007F
0x08	0x0080 through 0x00FF
0x09	0x0100 through 0x01FF
0x0A	0x0200 through 0x03FF
0x0B	0x0400 through 0x07FF
0x0C	0x0800 through 0x0FFF
0x0D	0x1000 through 0x1FFF
0x0E	0x2000 through 0x3FFF
0x0F	0x4000 through 0x7FFF
0x10	0x8000 through 0xFFFF

Table 4.1: Log field values

4.2 State definitions

The state of a node is defined using one or more state definitions. This section defines states used throughout this specification.

State definitions that are not required as part of this specification are defined in the Mesh Model specification [11] and follow the same format and architecture as mesh state definitions.

4.2.1 Composition Data

The Composition Data state contains information about a node, the elements it includes, and the supported models. The Composition Data is composed of a number of pages of information. Composition Data Page 0 is mandatory. All other pages are optional. All Composition Data Pages not defined in this specification are reserved for future use.

The size of the state shall not exceed the maximum useful access payload size (Table 3.42).

4.2.1.1 Composition Data Page 0

The format of the Composition Data Page 0 is defined in Table 4.2.

Field	Size (octets)	Notes
CID	2	Contains a 16-bit company identifier assigned by the Bluetooth SIG (the list is available at [6])
PID	2	Contains a 16-bit vendor-assigned product identifier
VID	2	Contains a 16-bit vendor-assigned product version identifier
CRPL	2	Contains a 16-bit value representing the minimum number of replay protection list entries in a device (see Section 3.8.8)
Features	2	Contains a bit field indicating the device features, as defined in Table 4.3
Elements	variable	Contains a sequence of element descriptions

Table 4.2: Composition Data Page 0 fields

The Features field contains a bit field indicating the node capabilities as defined in Section 3.2. The format of the Features field is defined in Table 4.3.

Bit	Feature	Notes
0	Relay	Relay feature support: 0 = False, 1 = True
1	Proxy	Proxy feature support: 0 = False, 1 = True
2	Friend	Friend feature support: 0 = False, 1 = True
3	Low Power	Low Power feature support: 0 = False, 1 = True



Bit	Feature	Notes
4–15	RFU	Reserved for Future Use

Table 4.3: Features field format

The Elements field contains a sequence of one or more element descriptions. The format of each element description is defined in Table 4.4.

Field	Size (octets)	Notes
Loc	2	Contains a location descriptor
NumS	1	Contains a count of SIG Model IDs in this element
NumV	1	Contains a count of Vendor Model IDs in this element
SIG Models	variable	Contains a sequence of NumS SIG Model IDs
Vendor Models	variable	Contains a sequence of NumV Vendor Model IDs

Table 4.4: Element description format

The Loc field contains a location description as defined in the GATT Bluetooth Namespace Descriptors section of the Bluetooth SIG Assigned Numbers [4]. Values not defined in the GATT Units table are Reserved for Future Use.

The SIG Models field contains a sequence of NumS SIG Model IDs. For each extended model included in this sequence, all models it extends shall also be included.

The Vendor Models field contains a sequence of NumV Vendor Model IDs.

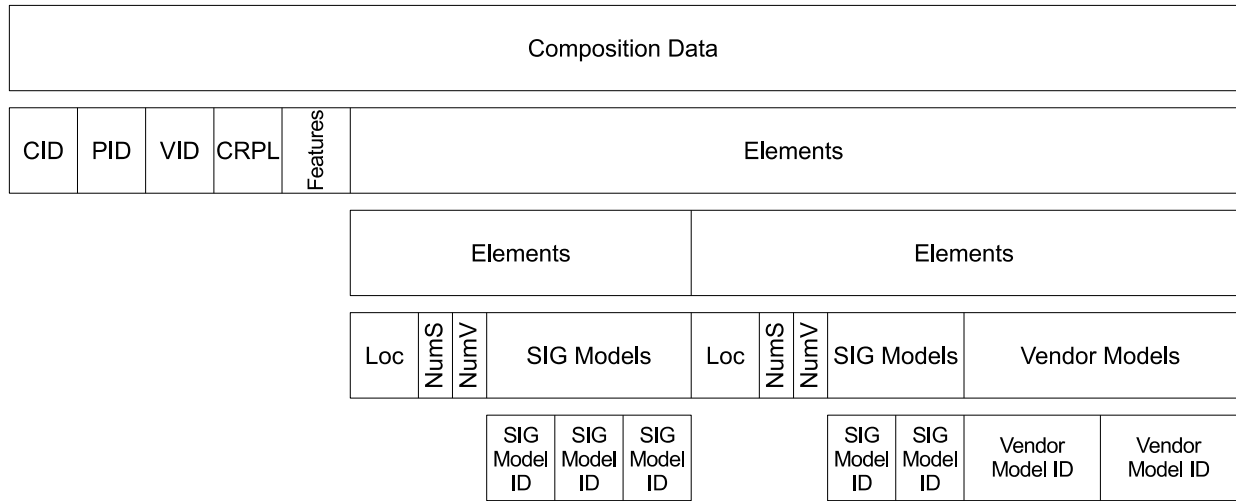


Figure 4.1: Composition Data Page 0 format



The example in [Figure 4.1](#) shows a Composition Data Page 0 with two elements. Each element includes the location, the number of SIG Model IDs, and the number of Vendor Model IDs. In this example, the first element has three SIG Model IDs and no Vendor Model IDs, and the second element has two SIG Model IDs and two Vendor Model IDs.

4.2.2 Model Publication

The Model Publication state is a composite state that controls parameters of messages that are published by a model. The state includes a Publish Address, a Publish Period, a Publish AppKey Index, a Publish Friendship Credential Flag, a Publish TTL, a Publish Retransmission Count, and a Publish Retransmit Interval Steps. Within an element, each model has a separate instance of Model Publication state. It is highly recommended that models defined by higher layer specifications use instances of the Model Publication state to control the publishing of messages.

4.2.2.1 Publish Address

The Publish Address state determines the destination address in messages sent by a model. The publish address shall be the unassigned address, a unicast address, a Label UUID, or a group address.

When the publication of the model is disabled, the Publish Address of the model is set to the unassigned address.

If the publish address of the model is the unassigned address, the model is inactive: it does not send any unsolicited messages out and can only send a response message to an incoming acknowledged message.

4.2.2.2 Publish Period

The Publish Period state determines the interval at which status messages are published by a model. This is a 1-octet value and consists of two fields: a 2-bit field representing the step resolution and a 6-bit field representing the number of steps. The format of this state is defined in [Table 4.5](#).

Field	Size (bits)	Description
Number of Steps	6	The number of steps
Step Resolution	2	The resolution of the Number of Steps field

Table 4.5: Publish Period format

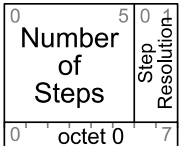


Figure 4.2: Publish Period format

The Step Resolution field enumerates the resolution of the Number of Steps field and the values are defined in [Table 4.6](#).



Value	Description
0b00	The Step Resolution is 100 milliseconds
0b01	The Step Resolution is 1 second
0b10	The Step Resolution is 10 seconds
0b11	The Step Resolution is 10 minutes

Table 4.6: Step Resolution values

The Number of Steps field is a value representing the number of steps and the values are defined in [Table 4.7](#).

Value	Description
0x00	Publish Period is disabled
0x01–0x3F	The number of steps

Table 4.7: Number of Steps values

The Publish Period is calculated using the formula:

$$\text{Publish Period} = \text{Step Resolution} * \text{Number of Steps}$$

For example, if the Step Resolution is 0b10 and the Number of Steps is 0x31, then the Publish Period would be 490 seconds.

4.2.2.3 Publish AppKey Index

The Publish AppKey Index state is the global AppKey Index of the application key used in messages sent by a model. The Publish AppKey Index shall be in the model to AppKey List as defined in [Section 4.2.6](#).

4.2.2.4 Publish Friendship Credentials Flag

The Publish Friendship Credential Flag is a 1-bit state controlling the credentials used to publish messages from a model. The Publish Friendship Credentials Flag values are described in [Table 4.8](#).

Value	Description
0	Master security material is used for Publishing
1	Friendship security material is used for Publishing

Table 4.8: Publish Friendship Credential Flag values

When Publish Friendship Credential Flag is set to 1 and the friendship security material is not available, the master security material shall be used.

4.2.2.5 Publish TTL

The Publish TTL state determines the TTL value for outgoing messages published by the model and the values are defined in [Table 4.9](#). Setting Publish TTL to 0xFF will make the messages use the Default TTL as defined in [Section 4.2.7](#).



Value	Description
0x00–0x7F	The Publish TTL value, represented as a 1-octet integer
0x80–0xFE	Prohibited
0xFF	Use Default TTL

Table 4.9: Publish TTL values

Note: If the Publish TTL state is set to 1, the outgoing messages are published to local elements only, as defined in Section 3.4.5.

4.2.2.6 Publish Retransmit Count

The Publish Retransmit Count state is a 3-bit value controlling the number of times that a message published by a model will be retransmitted. For example, a value of 0b000 represents no retransmissions, and a value of 0b111 represents 7 retransmissions.

4.2.2.7 Publish Retransmit Interval Steps

The Publish Retransmit Interval Steps state is a 5-bit value controlling the interval between retransmissions of a message that is published by a model. The state represents the number of 50-millisecond steps that shall transpire before a message that was published by a model is retransmitted.

The retransmission interval is calculated using the following formula:

$$\text{retransmission interval} = (\text{Publish Retransmit Interval Steps} + 1) * 50$$

For example, a value of 0b10000 represents an interval of 850 milliseconds.

4.2.3 Subscription List

The Subscription List state is a list of group addresses and Label UUIDs.

The Subscription List is used by a model when receiving access messages as defined in Section 3.7.4.2. It is highly recommended that models defined by higher layer specifications use instances of the Subscription List state to control the receiving of messages.

Within an element, each model has a separate instance of a Subscription List, unless the model extends another model on that element. Instances of models that extend other models (i.e., all models within an extension relation tree) shall share a single instance of a Subscription List per element.

The size of the state shall not exceed the maximum useful access payload size (Table 3.42).

4.2.4 NetKey List

The NetKey List state is an indexed list of NetKeys.

Each entry in the NetKey List holds up to two key values: the old key value and the new key value. The use of the old key and the new key values is described in the Key Refresh procedure (see Section 3.10.4).

The NetKey List shall contain a minimum of one NetKey.

The size of the state shall not exceed the maximum useful access payload size ([Table 3.42](#)).

4.2.5 AppKey List

The AppKey List state is an indexed list of AppKeys.

Each entry in the AppKey List holds an AppKey Index and up to two key values: the old key value and the new key value. The use of the old key and the new key values is described in the Key Refresh procedure (see [Section 3.10.4](#)).

The size of the state shall not exceed the maximum useful access payload size ([Table 3.42](#)).

4.2.6 Model to AppKey List

The Model to AppKey List state is a list of relationships between models and AppKeys. A model may be associated with one or more AppKeys.

The size of the state shall not exceed the maximum useful access payload size ([Table 3.42](#)).

4.2.7 Default TTL

The Default TTL state determines the TTL value used when sending messages. The Default TTL is applied by the access layer unless the application specifies a TTL. The Default TTL values are defined in [Table 4.10](#).

Value	Description
0x00, 0x02–0x7F	The Default TTL state
0x01, 0x80–0xFF	Prohibited

Table 4.10: Default TTL values

4.2.8 Relay

The Relay state indicates support for the Relay feature. If the Relay feature is supported, then this also indicates and controls whether the Relay feature is enabled or disabled. The values are defined in [Table 4.11](#).

Value	Description
0x00	The node support Relay feature that is disabled
0x01	The node supports Relay feature that is enabled
0x02	Relay feature is not supported
0x03–0xFF	Prohibited

Table 4.11: Relay values

If Relay feature is not supported, the Relay state value shall be 0x02 and not be changed.

If Relay feature is supported, the Relay state value 0x02 shall not be used.

4.2.9 Attention Timer

The Attention Timer state determines if the Attention Timer state is on or off. This is generally intended to allow an element to attract human attention and, among others, is used during provisioning (see Section 5.4.2).

A device may not support the Attention Timer. On a device that does not support the Attention Timer, the Attention Timer state shall always be set to zero.

If the Attention Timer is non-zero for an element, Attention Timer state is on. If the Attention Timer is zero for an element, the Attention Timer state is off.

When the Attention Timer state is on, the value determines how long the element shall remain attracting human's attention. The element does that by behaving in a human-recognizable way (e.g., a lamp flashes, a motor makes noise, an LED blinks). The exact behavior is implementation specific and depends on the type of device. Normal behavior of the element is still active, although the method of identification may override the physical state of the device.

The Attention Timer is a momentary state, active for a time indicated by its value, in seconds. The value is decremented every second by 1 until it reaches zero. The values for this state are defined in Table 4.12.

Value	Description
0x00	Off
0x01–0xFF	On, remaining time in seconds

Table 4.12: Attention Timer values

4.2.10 Secure Network Beacon

The Secure Network Beacon state determines if a node is periodically broadcasting Secure Network beacon messages (see Section 3.9.3). The values for this state are defined in Table 4.13.

Value	Description
0x00	The node is not broadcasting a Secure Network beacon
0x01	The node is broadcasting a Secure Network beacon
0x02–0xFF	Prohibited

Table 4.13: Secure Network Beacon values

4.2.11 GATT Proxy

The GATT Proxy state indicates if the Proxy feature (see Section 3.4.6.2) is supported. If the feature is supported, the state indicates and controls the Proxy feature.

Note: If the Proxy feature is disabled, a GATT client device can connect over GATT to that node for configuration and control. Messages from the GATT bearer are not relayed to the advertising bearer.



The values for this state are defined in [Table 4.14](#).

Value	Description
0x00	The Proxy feature is supported and disabled
0x01	The Proxy feature is supported and enabled
0x02	The Proxy feature is not supported
0x03–0xFF	Prohibited

Table 4.14: GATT Proxy values

If the Proxy feature is not supported, the GATT Proxy state value shall be 0x02 and shall not be changed.

If the Proxy feature is supported, the GATT Proxy state value 0x02 shall not be used.

4.2.12 Node Identity

The Node Identity state determines if a node is advertising with Node Identity messages on a subnet (see [Section 7.2.2.2.3](#)). If the Mesh Proxy Service is exposed, the node can be configured to advertise with Node Identity on a subnet. The values for this state are defined in [Table 4.15](#).

Value	Description
0x00	Advertising with Node Identity for a subnet is stopped
0x01	Advertising with Node Identity for a subnet is running
0x02	Advertising with Node Identity is not supported
0x03–0xFF	Prohibited

Table 4.15: Node Identity values

If the Mesh Proxy Service is not exposed, the Node Identity state value shall be 0x02 and not be changed.

If the Mesh Proxy Service is exposed, the Node Identity state value 0x02 shall not be used.

4.2.13 Friend

The Friend state indicates support for the Friend feature. If Friend feature is supported, then this also indicates and controls whether Friend feature is enabled or disabled. The values for this state are defined in [Table 4.16](#).

Value	Description
0x00	The node supports Friend feature that is disabled
0x01	The node supports Friend feature that is enabled
0x02	The Friend feature is not supported
0x03–0xFF	Prohibited

Table 4.16: Friend values



If the Friend feature is not supported, the Friend state value shall be 0x02 and not be changed.

If the Friend feature is supported, the Friend state value 0x02 shall not be used.

If the Friend feature is supported and the Friend state changes to value 0x00 and if a node is a friend for one or more Low Power nodes, the node shall terminate all friend relationships and clear the associated Friend Queue.

4.2.14 Key Refresh Phase

The Key Refresh Phase state indicates and controls the Key Refresh procedure (see Section 3.10.4) for each NetKey in the NetKey List. The values for this state are defined in Table 4.17.

Value	Description
0x00	Normal operation; Key Refresh procedure is not active
0x01	First phase of Key Refresh procedure
0x02	Second phase of Key Refresh procedure
0x03–0xFF	Prohibited

Table 4.17: Key Refresh Phase state values

Table 4.18 defines all possible transitions of the Key Refresh Phase state that can be controlled using this state. All other transitions are handled internally (e.g., the transition from 0x00 to 0x01 when a device receives a key update) by Key Refresh procedure.

Old State	Transition	New State	Description
0x00	0x03	0x00	Transition 3 from Key Refresh Phase 0x00 does not cause any state change.
0x01	0x02	0x02	Transition 2 from Key Refresh Phase 0x01 moves to Key Refresh Phase 0x02
0x01	0x03	0x00	Transition 3 from Key Refresh Phase 0x01 invokes Key Refresh Phase 3 and then moves to Key Refresh Phase 0x00.
0x02	0x02	0x02	Transition 2 from Key Refresh Phase 0x02 does not cause any state change.
0x02	0x03	0x00	Transition 3 from Key Refresh Phase 0x02 invokes Key Refresh Phase 3 and then moves to Key Refresh Phase 0x00.

Table 4.18: Controllable Key Refresh transition values



4.2.15 Health Fault

The Health Fault state is a composite state that represent a warning or an error condition of an element.

The Health Fault state is identified by Company ID and may be present in the node for more than one Company ID.

4.2.15.1 Current Fault

The Current Fault state is a 1-octet value of the most recently performed self-test and an array containing a sequence of 1-octet values, each representing the current warning or error condition of an element. The format of this state is defined in [Table 4.19](#).

Field	Size	Notes
Test ID	1	Identifier of a most recently performed self-test
FaultArray	N	Array of current faults

Table 4.19: Current Fault format

Values for the Test ID are defined in [Table 4.20](#).

Value	Description
0x00	Standard test
0x01–0xFF	Vendor specific test

Table 4.20: Test ID values

The FaultArray values are defined in [Table 4.21](#).

Values 0x01–0x7F are Bluetooth assigned numbers, with values representing specific warning and error conditions. Values 0x80–0xFF are vendor specific and may be used to represent warnings and errors defined by device manufacturers. The Current Fault FaultArray is empty when no warning or error condition is present. The FaultArray reflects a real time state. This means when a fault condition arises, a corresponding record is present in the FaultArray and when a fault condition is not present, the corresponding record is removed from the FaultArray automatically.

A warning indicates the state of an element that is operating within the design limits but close to them.

An error indicates that the state of an element is outside the design limits and may not perform its functions.

Value	Description
0x00	No Fault
0x01	Battery Low Warning
0x02	Battery Low Error
0x03	Supply Voltage Too Low Warning
0x04	Supply Voltage Too Low Error



Value	Description
0x05	Supply Voltage Too High Warning
0x06	Supply Voltage Too High Error
0x07	Power Supply Interrupted Warning
0x08	Power Supply Interrupted Error
0x09	No Load Warning
0x0A	No Load Error
0x0B	Overload Warning
0x0C	Overload Error
0x0D	Overheat Warning
0x0E	Overheat Error
0x0F	Condensation Warning
0x10	Condensation Error
0x11	Vibration Warning
0x12	Vibration Error
0x13	Configuration Warning
0x14	Configuration Error
0x15	Element Not Calibrated Warning
0x16	Element Not Calibrated Error
0x17	Memory Warning
0x18	Memory Error
0x19	Self-Test Warning
0x1A	Self-Test Error
0x1B	Input Too Low Warning
0x1C	Input Too Low Error
0x1D	Input Too High Warning
0x1E	Input Too High Error
0x1F	Input No Change Warning
0x20	Input No Change Error
0x21	Actuator Blocked Warning
0x22	Actuator Blocked Error
0x23	Housing Opened Warning
0x24	Housing Opened Error
0x25	Tamper Warning
0x26	Tamper Error

Value	Description
0x27	Device Moved Warning
0x28	Device Moved Error
0x29	Device Dropped Warning
0x2A	Device Dropped Error
0x2B	Overflow Warning
0x2C	Overflow Error
0x2D	Empty Warning
0x2E	Empty Error
0x2F	Internal Bus Warning
0x30	Internal Bus Error
0x31	Mechanism Jammed Warning
0x32	Mechanism Jammed Error
0x33–0x7F	Reserved for Future Use
0x80–0xFF	Vendor Specific Warning / Error

Table 4.21: Fault values

4.2.15.2 Registered Fault

The Registered Fault state is a 1-octet value of the most recently performed self-test and a shadow array of the Current Fault FaultArray. The format of this state is defined in [Table 4.22](#).

Field	Size	Notes
Test ID	1	Identifier of a most recently performed self-test
FaultArray	N	Array of registered faults

Table 4.22: Registered Fault format

Values for the Test ID are defined in [Table 4.23](#).

Value	Description
0x00	Standard test
0x01–0xFF	Vendor specific test

Table 4.23: Test ID values

Whenever a fault condition has been present in the Current Fault state (see [Section 4.2.15.1](#)), the corresponding record is added to the Registered Fault FaultArray. The FaultArray is cleared with a dedicated Health Fault Clear message (see [Section 4.3.3.3](#)).

4.2.16 Health Fast Period Divisor

The Health Fast Period Divisor state is a 1-octet value that controls the increased cadence of publishing Health Current Status messages.

The value range for the Health Fast Period Divisor state is 0 through 15, all other values are prohibited. This is used to divide the Health Publish Period by 2^n where the n is the value of the Health Fast Period Divisor state.

4.2.17 Heartbeat Publication

The Heartbeat Publication state is a composite state that controls sending of periodical Heartbeat transport control messages.

4.2.17.1 Heartbeat Publication Destination

The Heartbeat Publication Destination state determines the destination address for Heartbeat messages. The Heartbeat Publication Destination shall be the unassigned address, a unicast address, or a group address, all other values are Prohibited.

Note: If the Heartbeat Publication Destination is set to the unassigned address, the Heartbeat messages are not being sent.

4.2.17.2 Heartbeat Publication Count

The Heartbeat Publication Count state is a 16-bit value that controls the number of periodical Heartbeat transport control messages to be sent. When set to 0xFFFF, it is not decremented after sending each Heartbeat message. When set to 0x0000, Heartbeat messages are not sent. When set to a value greater than or equal to 0x0001 or less than or equal to 0xFFFE, it is decremented after sending each Heartbeat message.

The Heartbeat Publication Count Log is a representation of the Heartbeat Publication Count value. The Heartbeat Publication Count Log and Heartbeat Publication Count with the value 0x00 and 0x0000 are equivalent. The Heartbeat Publication Count Log value of 0xFF is equivalent to the Heartbeat Publication count value of 0xFFFF. The Heartbeat Publication Count Log value between 0x01 and 0x11 shall represent that smallest integer n where $2^{(n-1)}$ is greater than or equal to the Heartbeat Publication Count value. For example, if the Heartbeat Publication Count value is 0x0579, then the Heartbeat Publication Count Log value would be 0x0C.

Value	Description
0x00	Heartbeat messages are not being sent periodically
0x01–0x11	Number of Heartbeat messages, $2^{(n-1)}$, that remain to be sent
0x12-0xFE	Prohibited
0xFF	Heartbeat messages are being sent indefinitely

Table 4.24: Heartbeat Publication Count Log values

4.2.17.3 Heartbeat Publication Period Log

The Heartbeat Publication Period Log state is an 8-bit value that controls the cadence of periodical Heartbeat transport control messages. The value is represented as $2^{(n-1)}$ seconds. For example, the value 0x04 would have a publication period of 8 seconds, and the value 0x07 would have a publication period of 64 seconds. The values for this state are defined in [Table 4.25](#).

Value	Description
0x00	Heartbeat messages are not being sent periodically
0x01–0x11	Smallest integer n, where $2^{(n-1)}$ is greater than or equal to the Heartbeat Publication Count value
0x12–0xFF	Prohibited

Table 4.25: Heartbeat Publication Period Log values

4.2.17.4 Heartbeat Publication TTL

The Heartbeat Publication TTL state determines the TTL value used when sending Heartbeat messages. The values for this state are defined in [Table 4.26](#).

Value	Description
0x00–0x7F	The Heartbeat Publication TTL state
0x80–0xFF	Prohibited

Table 4.26: Heartbeat Publication TTL values

4.2.17.5 Heartbeat Publication Features

The Heartbeat Publication Features state determines the features that trigger sending Heartbeat messages when changed. The values for this state are defined in [Table 4.27](#).

Bit	Feature	Notes
0	Relay	Relay feature change triggers a Heartbeat message: 0 = False, 1 = True
1	Proxy	Proxy feature change triggers a Heartbeat message: 0 = False, 1 = True
2	Friend	Friend feature change triggers a Heartbeat message: 0 = False, 1 = True
3	Low Power	Low Power feature change triggers a Heartbeat message: 0 = False, 1 = True
4–15	RFU	Reserved for Future Use

Table 4.27: Heartbeat Publication Feature values

4.2.17.6 Heartbeat Publication NetKey Index

The Heartbeat Publication NetKey Index state determines the global NetKey Index of the NetKey used to send Heartbeat messages.

4.2.18 Heartbeat Subscription

The Heartbeat Subscription state is a composite state that controls receiving of periodical Heartbeat transport control messages.

4.2.18.1 Heartbeat Subscription Source

The Heartbeat Subscription Source state determines the source address for Heartbeat messages a node shall process. The Heartbeat Subscription Source shall be the unassigned address or a unicast address, all other values are Prohibited.

If the Heartbeat Subscription Source is set to the unassigned address, the Heartbeat messages are not being processed.

4.2.18.2 Heartbeat Subscription Destination

The Heartbeat Subscription Destination state determines the destination address for Heartbeat messages. This can be used by nodes to configure a proxy filter to allow them to receive Heartbeat messages, for example, nodes connected using a GATT bearer or in a friendship. The Heartbeat Subscription Destination shall be the unassigned address, the primary unicast address of the node, or a group address, all other values are Prohibited.

If the Heartbeat Subscription Destination is set to the unassigned address, the Heartbeat messages are not being processed.

4.2.18.3 Heartbeat Subscription Count

The Heartbeat Subscription Count state is a 16-bit counter that controls the number of periodical Heartbeat transport control messages received since receiving the most recent Config Heartbeat Subscription Set message. The counter stops counting at 0xFFFF. The values for this state are defined in [Table 4.28](#).

The Heartbeat Subscription Count Log is a representation of the Heartbeat Subscription Count value. The Heartbeat Subscription Count Log and Heartbeat Subscription Count with the value 0x00 and 0x0000 are equivalent. The Heartbeat Subscription Count Log value of 0xFF is equivalent to the Heartbeat Subscription count value of 0xFFFF. The Heartbeat Subscription Count Log value between 0x01 and 0x10 shall represent the Heartbeat Subscription Count value, using the transformation defined in [Table 4.1](#).

Value	Description
0x0000–0xFFFE	Number of Heartbeat messages received
0xFFFF	More than 0xFFFE messages have been received

Table 4.28: Heartbeat Subscription Count values

4.2.18.4 Heartbeat Subscription Period Log

The Heartbeat Subscription Period state is a 16-bit value that controls the period for processing periodical Heartbeat transport control messages. When set to 0x0000, Heartbeat messages are not being processed. When set to a value greater than or equal to 0x0001, Heartbeat messages are being processed. The values for this state are defined in [Table 4.29](#).



The Heartbeat Subscription Period Log is a representation of the Heartbeat Subscription Period value. The Heartbeat Subscription Period Log and Heartbeat Subscription Period with the value 0x00 and 0x0000 are equivalent. The Heartbeat Subscription Period Log value between 0x01 and 0x11 shall represent the Heartbeat Subscription Period value, using the transformation defined in [Table 4.1](#).

Value	Description
0x00	Heartbeat messages are not being processed
0x01–0x11	Remaining period in $2^{(n-1)}$ seconds for processing periodical Heartbeat messages
0x12–0xFF	Prohibited

Table 4.29: Heartbeat Subscription Period values

4.2.18.5 Heartbeat Subscription Min Hops

The Heartbeat Subscription Min Hops state determines the minimum hops value registered when receiving Heartbeat messages since receiving the most recent Config Heartbeat Subscription Set message. The values for this state are defined in [Table 4.30](#).

Value	Description
0x00	No Heartbeat messages have been received
0x01–0x7F	The Heartbeat Subscription Min Hops state
0x80–0xFF	Prohibited

Table 4.30: Heartbeat Subscription Min TTL values

4.2.18.6 Heartbeat Subscription Max Hops

The Heartbeat Subscription Max Hops state determines the maximum hops value registered when receiving Heartbeat messages since receiving the most recent Config Heartbeat Subscription Set message. The values for this state are defined in [Table 4.31](#).

Value	Description
0x00	No Heartbeat messages have been received.
0x01–0x7F	The Heartbeat Subscription Max Hops state
0x80–0xFF	Prohibited

Table 4.31: Heartbeat Subscription Max TTL values

4.2.19 Network Transmit

The Network Transmit state is a composite state that controls the number and timing of the transmissions of Network PDU originating from a node.

The state includes a Network Transmit Count field and a Network Transmit Interval Steps field.

There is a single instance of this state for the node.



4.2.19.1 Network Transmit Count

The Network Transmit Count field is a 3-bit value that controls the number of message transmissions of the Network PDU originating from the node. The number of transmissions is the Transmit Count + 1.

For example a value of 0b000 represents a single transmission and a value of 0b111 represents 8 transmissions.

4.2.19.2 Network Transmit Interval Steps

The Network Transmit Interval Steps field is a 5-bit value representing the number of 10 millisecond steps that controls the interval between message transmissions of Network PDUs originating from the node.

The transmission interval is calculated using the formula:

$$\text{transmission interval} = (\text{Network Retransmit Interval Steps} + 1) * 10$$

Each transmission should be perturbed by a random value between 0 to 10 milliseconds between each transmission.

For example, a value of 0b10000 represents a transmission interval between 170 and 180 milliseconds between each transmission.

Note: A bearer (for example, the advertising bearer) may impose restrictions on the set of intervals that it considers valid, and therefore the interval used may be larger than the value of the state.

4.2.20 Relay Retransmit

The Relay Retransmit state is a composite state that controls parameters of retransmission of the Network PDU relayed by the node.

The state includes a Relay Retransmit Count and a Relay Retransmit Interval Steps states.

There is a single instance of this state for the node.

4.2.20.1 Relay Retransmit Count

The Relay Retransmit Count field is a 3-bit value that controls the number of message retransmissions of the Network PDU relayed by the node. The Relay Retransmit Count + 1 is the number of times that packet is transmitted for each packet that is relayed.

For example, a value of 0b000 represents a single transmission with no retransmissions, and a value of 0b111 represents a single transmission and 7 retransmissions for a total of 8 transmissions.

4.2.20.2 Relay Retransmit Interval Steps

The Relay Retransmit Interval Steps field is a 5-bit value representing the number of 10 millisecond steps that controls the interval between message retransmissions of the Network PDU relayed by the node.

The retransmission interval is calculated using the formula:

$$\text{retransmission interval} = (\text{Relay Retransmit Interval Steps} + 1) * 10$$



Note: At the link layer, each transmission is perturbed by a random value from 0 to 10 milliseconds from the previous transmission.

Note: A bearer (for example, the advertising bearer) may impose restrictions on the set of intervals that it considers valid, and therefore the interval used may be larger than the value of the state.

4.2.21 PollTimeout List

The PollTimeout List state is a list of current values of PollTimeout timer of the Low Power nodes within a Friend node.

For each Low Power node, the entry in the PollTimeout List holds the current value of the PollTimeout timer. If there are multiple friendship relationships set up on multiple subnets, the value held on the list is the minimum value of all PollTimeout timers for all friendship relationships the Friend Node has established with the Low Power node.

The list is indexed by Low Power node primary element address.

Value	Description
0x000000	The node is no longer a Friend node of the Low Power node identified by the LPNAddress
0x000001 through 0x000009	Prohibited
0x00000A through 0x34BBFF	The PollTimeout timer value in units of 100 milliseconds
0x34BC00 through 0xFFFFF	Prohibited

Table 4.32: PollTimeout Timer values

If the Friend feature is not supported or the Friend feature is supported and disabled, the current value of the PollTimeout List state for any Low Power node shall be set to 0x000000.

If the Friend feature is supported and enabled and the Friend node has not established friendship with the Low Power node identified by a primary element address, the current value of the PollTimeout List state for that Low Power node shall be set to 0x000000.

The size of the state shall not exceed the maximum useful access payload size (Table 3.42).

4.3 Message definitions

This section defines messages used throughout this specification. Each message has an opcode and zero or more parameters, as defined in Section 3.7.3. Messages are also defined as either unacknowledged or acknowledged. Acknowledged messages have defined responses that shall be used to confirm execution.

Message definitions that are not required as part of this specification are defined in the Mesh Model specification [11] and follow the same format and architecture as mesh message definitions.

4.3.1 Supplemental parameter requirements

This section contains supplemental requirements for the handling of some parameters. Parameter values that do not conform to these requirements shall be considered Reserved for Future Use.

4.3.1.1 Key indexes

Both NetKeys and AppKeys are 16-octets long and thus do not fit in a single-segment message. The generic segmentation and reassembly mechanism is used to transport new keys to nodes.

A Configuration Client maintains two indexed global lists of NetKeys and AppKeys – the NetKey List and AppKey List. Each key shall have a unique global index in the appropriate list and this index is used to identify that key in the module.

Global key indexes are 12 bits long. Some messages include one, two or multiple key indexes. To enable efficient packing, two key indexes are packed into three octets. Where an odd number of key indexes need to be packed, all but the last key index are packed into sequences of three octets (see [Figure 4.3](#)), and the last key index is packed into two octets (see [Figure 4.4](#)). Where an even number of key indexes need to be packed, they are all packed into sequences of three octets.

To pack two key indexes into three octets, 8 LSbs of first key index value are packed into the first octet, placing the remaining 4 MSBs into 4 LSbs of the second octet. The first 4 LSbs of the second 12-bit key index are packed into the 4 MSBs of the second octet with the remaining 8 MSBs into the third octet.

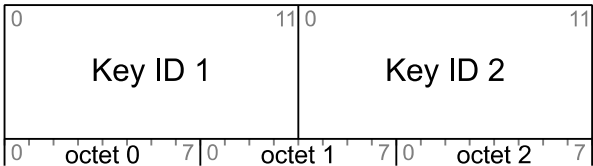


Figure 4.3: Packing of two 12-bit key Indexes into three octets

To pack one key index into two octets, 8 LSbs of first key index value are packed into the first octet, placing the remaining 4 MSBs into 4 LSbs of the second octet, and the 4 MSBs of the second octet shall be set to 0.

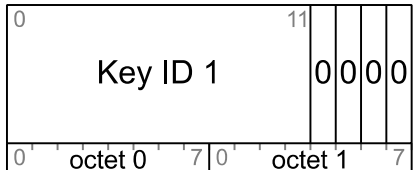


Figure 4.4: Encoding of one 12-bit key index into two octets

4.3.1.2 Element addresses

Messages may contain fields carrying network addresses, such as an element address, a group address, or a virtual address. Such fields may be used by the access layer and other upper layers, but shall not be used by the network layer, the lower transport layer, nor the upper transport layer.



4.3.1.3 Model identifiers

Messages may contain fields carrying Model IDs. Such fields may have a 2-octet size or a 4-octet size to accommodate either a SIG Model ID (16-bit) or a Vendor Model ID (32-bit).

4.3.1.4 Variable length parameters

When a variable length field is used, it shall be the last field for a message, and the size of the field is determined based on the message length information provided by lower layers. There shall only be one sequence of consecutive optional fields or a variable length parameter.

4.3.1.5 Optional parameters

When optional fields are used, they shall be the last fields for a message and the presence of the fields is determined based on the message length information provided by lower layers. There shall only be one sequence of consecutive optional fields or a variable length parameter.

4.3.2 Configuration messages

Configuration messages are used to control states that determine network-related behaviors of the node, manipulate network and application keys, as well as perform other operations that require an elevated level of security. Every configuration message shall be encrypted and authenticated using a DevKey.

Because DevKeys are unique for every node, configuration messages shall be sent only to unicast addresses.

4.3.2.1 Config Beacon Get

The Config Beacon Get is an acknowledged message used to get the current Secure Network Beacon state of a node (see Section 4.2.10).

The response to a Config Beacon Get message is a Config Beacon Status message.

There are no Parameters for this message.

4.3.2.2 Config Beacon Set

The Config Beacon Set is an acknowledged message used to set the Secure Network Beacon state of a node (see Section 4.2.10).

The response to a Config Beacon Set message is a Config Beacon Status message.

Field	Size (octets)	Notes
Beacon	1	New Secure Network Beacon state

Table 4.33: Config Beacon Set message parameters

The Beacon field shall provide the new Secure Network Beacon state of the node (see Section 4.2.10).



4.3.2.3 Config Beacon Status

The Config Beacon Status is an unacknowledged message used to report the current Secure Network Beacon state of a node (see Section 4.2.10).

Field	Size (octets)	Notes
Beacon	1	Secure Network Beacon state

Table 4.34: Config Beacon Status message parameters

The Beacon field shall provide the current Secure Network Beacon state of the node (see Section 4.2.10).

4.3.2.4 Config Composition Data Get

The Config Composition Data Get is an acknowledged message used to read one page of the Composition Data (see Section 4.2.1).

The response to a Config Composition Data Get message is a Config Composition Data Status message.

Field	Size (octets)	Notes
Page	1	Page number of the Composition Data

Table 4.35: Config Composition Data Get message parameters

The Page field shall identify the Composition Data Page number that is being read.

4.3.2.5 Config Composition Data Status

The Config Composition Data Status is an unacknowledged message used to report a single page of the Composition Data (see Section 4.2.1).

This message uses a single octet opcode to maximize the size of a payload.

Field	Size (octets)	Notes
Page	1	Page number of the Composition Data
Data	variable	Composition Data for the identified page

Table 4.36: Config Composition Data Status message parameters

The Page field shall identify the Composition Data Page number.

The Data field shall contain the identified single page of the Composition Data.

4.3.2.6 Config Default TTL Get

The Config Default TTL Get is an acknowledged message used to get the current Default TTL state of a node.



The response to a Config Default TTL Get message is a Config Default TTL Status message.

There are no Parameters for this message.

4.3.2.7 Config Default TTL Set

The Config Default TTL Set is an acknowledged message used to set the Default TTL state of a node (see Section 4.2.7).

The response to a Config Default TTL Set message is a Config Default TTL Status message.

Parameter	Size (octets)	Notes
TTL	1	New Default TTL value

Table 4.37: Config Default TTL Set message parameters

The TTL field shall identify a new Default TTL for the node (see Section 4.2.7).

4.3.2.8 Config Default TTL Status

The Config Default TTL Status is an unacknowledged message used to report the current Default TTL state of a node (see Section 4.2.7).

Parameters	Size (octets)	Notes
TTL	1	Default TTL

Table 4.38: Config Default TTL Status message parameters

The TTL field shall identify the Default TTL for the node, as defined in Default TTL (see Section 4.2.7).

4.3.2.9 Config GATT Proxy Get

The Config GATT Proxy Get is an acknowledged message used to get the current GATT Proxy state of a node (see Section 4.2.11).

The response to a Config GATT Proxy Get message is a Config GATT Proxy Status message.

There are no Parameters for this message.

4.3.2.10 Config GATT Proxy Set

The Config GATT Proxy Set is an acknowledged message used to set the GATT Proxy state of a node (see Section 4.2.11).

The response to a Config GATT Proxy Set message is a Config GATT Proxy Status message.



Field	Size (octets)	Notes
GATTProxy	1	New GATT Proxy state

Table 4.39: Config GATT Proxy Set message parameters

The GATTProxy field shall provide the new GATT Proxy state of the node (see Section 4.2.11).

4.3.2.11 Config GATT Proxy Status

The Config GATT Proxy Status is an unacknowledged message used to report the current GATT Proxy state of a node (see Section 4.2.11).

Field	Size (octets)	Notes
GATTProxy	1	GATT Proxy state

Table 4.40: Config GATT Proxy Status message parameters

The GATTProxy field shall provide the current GATT Proxy state of the node (see Section 4.2.11).

4.3.2.12 Config Relay Get

The Config Relay Get is an acknowledged message used to get the current Relay (see Section 4.2.8) and Relay Retransmit (see Section 4.2.20) states of a node.

The response to a Config Relay Get message is a Config Relay Status message.

There are no Parameters for this message.

4.3.2.13 Config Relay Set

The Config Relay Set is an acknowledged message used to set the Relay (see Section 4.2.8) and Relay Retransmit (see Section 4.2.20) states of a node.

The response to a Config Relay Set message is a Config Relay Status message.

Field	Size (bits)	Notes
Relay	8	Relay
RelayRetransmitCount	3	Number of retransmissions on advertising bearer for each Network PDU relayed by the node
RelayRetransmitIntervalSteps	5	Number of 10-millisecond steps between retransmissions

Table 4.41: Config Relay Set message parameters

The Relay field shall identify the new Relay state for the node, as defined in Section 4.2.8.

The RelayRetransmitCount field shall contain a new value for the Relay Retransmit Count state of a node (see Section 4.2.20.1).

The RelayRetransmitIntervalSteps field shall contain a new value for the Relay Retransmit Interval Steps state of a node (see Section 4.2.20.2).

4.3.2.14 Config Relay Status

The Config Relay Status is an unacknowledged message used to report the current Relay (see Section 4.2.8) and Relay Retransmit (see Section 4.2.20) states of a node.

Field	Size (bits)	Notes
Relay	8	Relay
RelayRetransmitCount	3	Number of retransmissions on advertising bearer for each Network PDU relayed by the node
RelayRetransmitIntervalSteps	5	Number of 10-millisecond steps between retransmissions

Table 4.42: Config Relay Status message parameters

The Relay field shall identify the current Relay state for the node, as defined in Section 4.2.8.

The RelayRetransmitCount field shall contain a new value for the Relay Retransmit Count state of a node (see Section 4.2.20.1).

The RelayRetransmitIntervalSteps field shall contain a new value for the Relay Retransmit Interval Steps state of a node (see Section 4.2.20.2).

4.3.2.15 Config Model Publication Get

The Config Model Publication Get is an acknowledged message used to get the publish address and parameters of an outgoing message that originates from a model.

The response to a Config Model Publication Get message is a Config Model Publication Status message.

Field	Size (octets)	Notes
ElementAddress	2	Address of the element
ModelIdentifier	2 or 4	SIG Model ID or Vendor Model ID

Table 4.43: Config Model Publication Get message parameters

The ElementAddress field is the unicast address of the element, all other address types are Prohibited.

The ModelIdentifier field is either a SIG Model ID or a Vendor Model ID that shall identify the model within the element.



4.3.2.16 Config Model Publication Set

The Config Model Publication Set is an acknowledged message used to set the Model Publication state (see Section 4.2.2) of an outgoing message that originates from a model.

The response to a Config Model Publication Set message is a Config Model Publication Status message.

The Config Model Publication Set message uses a single octet opcode to maximize the size of a payload.

Field	Size (bits)	Notes
ElementAddress	16	Address of the element
PublishAddress	16	Value of the publish address
AppKeyIndex	12	Index of the application key
CredentialFlag	1	Value of the Friendship Credential Flag
RFU	3	Reserved for Future Use
PublishTTL	8	Default TTL value for the outgoing messages
PublishPeriod	8	Period for periodic status publishing
PublishRetransmitCount	3	Number of retransmissions for each published message
PublishRetransmitIntervalSteps	5	Number of 50-millisecond steps between retransmissions
ModelIdentifier	16 or 32	SIG Model ID or Vendor Model ID

Table 4.44: Config Model Publication Set message parameters

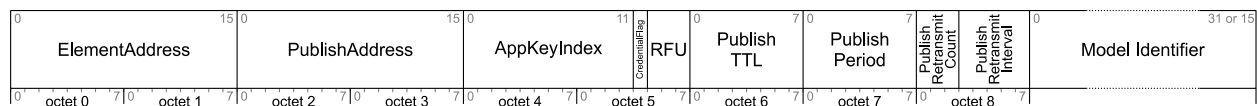


Figure 4.5: Config Model Publication Set format

The ElementAddress field is the unicast address of the element, all other address types are Prohibited.

The PublishAddress field shall contain the new Publish Address state (see Section 4.2.2.1) for the model. The value of PublishAddress field shall not be a virtual address.

The AppKeyIndex field shall contain the new Publish AppKey Index state (see Section 4.2.2.3).

The CredentialFlag field shall contain the new Publish Friendship Credentials Flag state (see Section 4.2.2.4).

The PublishTTL field shall contain the new Publish TTL state (see Section 4.2.2.5).

The PublishPeriod field shall contain a new value for the Publish Period state (see Section 4.2.2.2).

The PublishRetransmitCount field shall contain a new value for the Publish Retransmit Count state of an element (see Section 4.2.2.6).

The PublishRetransmitIntervalSteps field shall contain a new value for the Publish Retransmit Interval Steps state of an element (see Section 4.2.2.7).

The ModelIdentifier field is either a SIG Model ID or a Vendor Model ID that shall identify the model within the element.

4.3.2.17 Config Model Publication Virtual Address Set

The Config Model Publication Virtual Address Set is an acknowledged message used to set the model Publication state (see Section 4.2.2) of an outgoing message that originates from a model.

The response to a Config Model Publication Virtual Address Set message is a Config Model Publication Status message.

Field	Size (bits)	Notes
ElementAddress	16	Address of the element
PublishAddress	128	Value of the Label UUID publish address
AppKeyIndex	12	Index of the application key
CredentialFlag	1	Value of the Friendship Credential Flag
RFU	3	Reserved for Future Use
PublishTTL	8	Default TTL value for the outgoing messages
PublishPeriod	8	Period for periodic status publishing
PublishRetransmitCount	3	Number of retransmissions for each published message
PublishRetransmitIntervalSteps	5	Number of 50-millisecond steps between retransmissions
ModelIdentifier	16 or 32	SIG Model ID or Vendor Model ID

Table 4.45: Config Model Publication Virtual Address Set message parameters

The ElementAddress field is the unicast address of the element, all other address types are Prohibited.

The PublishAddress field shall contain the virtual address used as new Publish Address state (see Section 4.2.2.1) for the model.

The AppKeyIndex field shall contain the new Publish AppKey Index state (see Section 4.2.2.3).

The CredentialFlag field shall contain the new Publish Friendship Credentials Flag state (see Section 4.2.2.4).

The PublishTTL field shall contain the new Publish TTL state (see Section 4.2.2.5).

The PublishPeriod field shall contain a new value for the Publish Period state (see Section 4.2.2.2).



The PublishRetransmitCount field shall contain a new value for the Publish Retransmit Count state of an element (see Section 4.2.2.6).

The PublishRetransmitIntervalSteps field shall contain a new value for the Publish Retransmit Interval Steps state of an element (see Section 4.2.2.7).

The ModelIdentifier field is either a SIG Model ID or a Vendor Model ID that shall identify the model within the element.

4.3.2.18 Config Model Publication Status

The Config Model Publication Status is an unacknowledged message used to report the model Publication state (see Section 4.2.2) of an outgoing message that is published by the model.

Field	Size (bits)	Notes
Status	8	Status Code for the requesting message
ElementAddress	16	Address of the element
PublishAddress	16	Value of the publish address
AppKeyIndex	12	Index of the application key
CredentialFlag	1	Value of the Friendship Credential Flag
RFU	3	Reserved for Future Use
PublishTTL	8	Default TTL value for the outgoing messages
PublishPeriod	8	Period for periodic status publishing
PublishRetransmitCount	3	Number of retransmissions for each published message
PublishRetransmitIntervalSteps	5	Number of 50-millisecond steps between retransmissions
ModelIdentifier	16 or 32	SIG Model ID or Vendor Model ID

Table 4.46: Config Model Publication Status message parameters

The Status field shall identify the Status Code for the last operation on Config Model Publication parameters. The allowed values for Status codes and their meanings are documented in Section 4.3.5.

The ElementAddress field shall contain the unicast address of the element, all other address types are Prohibited.

The PublishAddress field shall contain the current Publish Address for the model. When using a Label UUID, the status message shall provide this value as the virtual address as defined in Section 3.4.2.3.

The AppKeyIndex is a global AppKey Index of the AppKey.

The CredentialFlag field shall contain the current value Publish Friendship Credentials Flag state (see Section 4.2.2.4).

The PublishTTL field shall contain the current value of the Publish TTL state (see Section 4.2.2.5) for outgoing messages published by the model within the element.



The PublishPeriod field shall contain the current value for the Publish Period state (see Section 4.2.2.2) for outgoing messages published by the model within the element.

The PublishRetransmitCount field shall contain a new value for the Publish Retransmit Count state of an element (see Section 4.2.2.6).

The PublishRetransmitIntervalSteps field shall contain a new value for the Publish Retransmit Interval Steps state of an element (see Section 4.2.2.7).

The ModelIdentifier field is either a SIG Model ID or a Vendor Model ID that shall identify the model within the element.

4.3.2.19 Config Model Subscription Add

The Config Model Subscription Add is an acknowledged message used to add an address to a Subscription List of a model (see Section 4.2.3).

The response to a Config Model Subscription Add message is a Config Model Subscription Status message.

Field	Size (octets)	Notes
ElementAddress	2	Address of the element
Address	2	Value of the address
ModelIdentifier	2 or 4	SIG Model ID or Vendor Model ID

Table 4.47: Config Model Subscription Add message parameters

The ElementAddress field is the unicast address of the element, all other address types are Prohibited.

The Address field shall contain the new address to be added to the Subscription List. The value of the Address field shall not be an unassigned address, unicast address, all-nodes address or virtual address.

The ModelIdentifier field is either a SIG Model ID or a Vendor Model ID that shall identify the model within the element.

4.3.2.20 Config Model Subscription Virtual Address Add

The Config Model Subscription Virtual Address Add is an acknowledged message used to add an address to a Subscription List of a model (see Section 4.2.3).

The response to a Config Model Subscription Virtual Address Add message is a Config Model Subscription Status message.



Field	Size (octets)	Notes
ElementAddress	2	Address of the element
Label	16	Value of the Label UUID
ModelIdentifier	2 or 4	SIG Model ID or Vendor Model ID

Table 4.48: Config Model Subscription Virtual Address Add message parameters

The ElementAddress field is the unicast address of the element, all other address types are Prohibited.

The Label field shall contain the Label UUID to be added to the Subscription List.

The ModelIdentifier field is either a SIG Model ID or a Vendor Model ID that shall identify the model within the element.

4.3.2.21 Config Model Subscription Delete

The Config Model Subscription Delete is an acknowledged message used to delete a subscription address from the Subscription List of a model (see Section 4.2.3).

The response to a Config Model Subscription Delete message is a Config Model Subscription Status message.

Field	Size (octets)	Notes
ElementAddress	2	Address of the element
Address	2	Value of the Address
ModelIdentifier	2 or 4	SIG Model ID or Vendor Model ID

Table 4.49: Config Model Subscription Delete message parameters

The ElementAddress field is the unicast address of the element, all other address types are Prohibited.

The Address field shall identify the address to be removed from the Subscription List. The value of the Address field shall not be an unassigned address, unicast address, all-nodes address or virtual address.

The ModelIdentifier field either is a SIG Model ID or a Vendor Model ID that shall identify the model within the element.

4.3.2.22 Config Model Subscription Virtual Address Delete

The Config Model Subscription Virtual Address Delete is an acknowledged message used to delete a subscription address from the Subscription List of a model (see Section 4.2.3).

The response to a Config Model Subscription Virtual Address Delete message is a Config Model Subscription Status message.

Field	Size (octets)	Notes
ElementAddress	2	Address of the element
Address	16	Value of the Label UUID
ModelIdentifier	2 or 4	SIG Model ID or Vendor Model ID

Table 4.50: Config Model Subscription Virtual Address Delete message parameters

The ElementAddress field is the unicast address of the element, all other address types are Prohibited.

The Address field shall contain the Label UUID used to identify the Address to be removed from the Subscription List.

The ModelIdentifier field is either a SIG Model ID or a Vendor Model ID that shall identify the model within the element.

4.3.2.23 Config Model Subscription Overwrite

The Config Model Subscription Overwrite is an acknowledged message used to discard the Subscription List and add an address to the cleared Subscription List of a model (see Section 4.2.3).

The response to a Config Model Subscription Overwrite message is a Config Model Subscription Status message.

Field	Size (octets)	Notes
ElementAddress	2	Address of the element
Address	2	Value of the Address
ModelIdentifier	2 or 4	SIG Model ID or Vendor Model ID

Table 4.51: Config Model Subscription Overwrite message parameters

The ElementAddress field is the unicast address of the element, all other address types are Prohibited.

The Address field shall contain the new address to be added to the Subscription List. The value of the Address field shall not be an unassigned address, unicast address, all-nodes address or virtual address.

The ModelIdentifier field is either a SIG Model ID or a Vendor Model ID that shall identify the model within the element.

4.3.2.24 Config Model Subscription Virtual Address Overwrite

The Config Model Subscription Virtual Address Overwrite is an acknowledged message used to discard the Subscription List and add an address to the cleared Subscription List of a model (see Section 4.2.3).

The response to a Config Model Subscription Virtual Address Overwrite message is a Config Model Subscription Status message.



Field	Size (octets)	Notes
ElementAddress	2	Address of the element
Address	16	Value of the Label UUID
ModelIdentifier	2 or 4	SIG Model ID or Vendor Model ID

Table 4.52: Config Model Subscription Virtual Address Overwrite message parameters

The ElementAddress field is the unicast address of the element, all other address types are Prohibited.

The Address field shall contain the Label UUID used as the new Address to be added to the Subscription List.

The ModelIdentifier field is either a SIG Model ID or a Vendor Model ID that shall identify the model within the element.

4.3.2.25 Config Model Subscription Delete All

The Config Model Subscription Delete All is an acknowledged message used to discard the Subscription List of a model (see Section 4.2.3).

The response to a Config Model Subscription Delete All message is a Config Model Subscription Status message.

Field	Size (octets)	Notes
ElementAddress	2	Address of the element
ModelIdentifier	2 or 4	SIG Model ID or Vendor Model ID

Table 4.53: Config Model Subscription Delete All message parameters

The ElementAddress field is the unicast address of the element, all other address types are Prohibited.

The ModelIdentifier field is a SIG Model ID or a Vendor Model ID that shall identify the model within the element.

4.3.2.26 Config Model Subscription Status

The Config Model Subscription Status is an unacknowledged message used to report a status of the operation on the Subscription List (see Section 4.2.3).

Field	Size (octets)	Notes
Status	1	Status Code for the requesting message.
ElementAddress	2	Address of the element
Address	2	Value of the address
ModelIdentifier	2 or 4	SIG Model ID or Vendor Model ID

Table 4.54: Config Model Subscription Status message parameters

The Status field shall identify the Status Code for the last operation on the Subscription List. The allowed values for Status codes and their meanings are documented in Section 4.3.5.

The ElementAddress field is the unicast address of the element, all other address types are Prohibited.

The value of the Address field shall contain the address that was used to modify the Subscription List or the unassigned address. When referencing the Label UUID, the virtual address shall be used. The value of the Address field shall not be a unicast address or the all-nodes address.

The ModelIdentifier field is a SIG Model ID or a Vendor Model ID that shall identify the model within the element.

4.3.2.27 Config SIG Model Subscription Get

The Config SIG Model Subscription Get is an acknowledged message used to get the list of subscription addresses of a model within the element. This message is only for SIG Models.

The response to a Config SIG Model Subscription Get message is a Config SIG Model Subscription List message.

Field	Size (octets)	Notes
ElementAddress	2	Address of the element
ModelIdentifier	2	SIG Model ID

Table 4.55: Config SIG Model Subscription Get message parameters

The ElementAddress field is the unicast address of the element, all other address types are Prohibited.

The ModelIdentifier field is a SIG Model ID that shall identify the model within the element.

4.3.2.28 Config SIG Model Subscription List

The Config SIG Model Subscription List is an unacknowledged message used to report all addresses from the Subscription List of the model (see Section 4.2.3). This message is only for SIG Models.

Field	Size (octets)	Notes
Status	1	Status Code for the requesting message
ElementAddress	2	Address of the element
ModelIdentifier	2	SIG Model ID
Addresses	variable	A block of all addresses from the Subscription List

Table 4.56: Config SIG Model Subscription List message parameters

The Status field shall identify the Status Code for the last operation on the Subscription List. The allowed values for Status codes and their meanings are documented in Section 4.3.5.



The ElementAddress field is the unicast address of the element, all other address types are Prohibited.

The ModelIdentifier field is a SIG Model ID that shall identify the model within the element.

The Addresses field shall identify all addresses from the Subscription List of an element. When using a Label UUID, the status message shall provide the value of the virtual address as defined in Section 3.4.2.3. The empty Subscription List results in Address field of zero length.

4.3.2.29 Config Vendor Model Subscription Get

The Config Vendor Model Subscription Get is an acknowledged message used to get the list of subscription addresses of a model within the element. This message is only for Vendor Models.

The response to a Config Vendor Model Subscription Get message is a Config Vendor Model Subscription List message.

Field	Size (octets)	Notes
ElementAddress	2	Address of the element
ModelIdentifier	4	Vendor Model ID

Table 4.57: Config Vendor Model Subscription Get message parameters

The ElementAddress field is the unicast address of the element, all other address types are Prohibited.

The ModelIdentifier field is a Vendor Model ID that shall identify the model within the element.

4.3.2.30 Config Vendor Model Subscription List

The Config Vendor Model Subscription List is an unacknowledged message used to report all addresses from the Subscription List of the model (see Section 4.2.3). This message is only for Vendor Models.

Field	Size (octets)	Notes
Status	1	Status Code for the requesting message
ElementAddress	2	Address of the element
ModelIdentifier	4	Vendor Model ID
Addresses	variable	A block of all addresses from the Subscription List

Table 4.58: Config Vendor Model Subscription List message parameters

The Status field shall identify the Status Code for the last operation on the Subscription List. The allowed values for Status codes and their meanings are documented in Section 4.3.5.

The ElementAddress field is the unicast address of the element, all other address types are Prohibited.

The ModelIdentifier field is a Vendor Model ID that shall identify the model within the element.



The Addresses field shall identify all addresses from the Subscription List of an element. When using a Label UUID, the status message shall provide the value of the virtual address as defined in Section 3.4.2.3. The empty Subscription List results in Address field of zero length.

4.3.2.31 Config NetKey Add

The Config NetKey Add is an acknowledged message used to add a NetKey to a NetKey List (see Section 4.2.4) on a node. The added NetKey is then used by the node to authenticate and decrypt messages it receives, as well as authenticate and encrypt messages it sends.

The response to a Config NetKey Add message is a Config NetKey Status message.

Field	Size (octets)	Notes
NetKeyIndex	2	NetKey Index
NetKey	16	NetKey

Table 4.59: Config NetKey Add message parameters

The NetKeyIndex field shall identify the global NetKey Index of the NetKey. The NetKeyIndex field shall be encoded as defined in Section 4.3.1.1.

The NetKey field shall contain the NetKey.

4.3.2.32 Config NetKey Update

The Config NetKey Update is an acknowledged message used to update a NetKey on a node. The updated NetKey is then used by the node to authenticate and decrypt messages it receives, as well as authenticate and encrypt messages it sends, as defined by the Key Refresh procedure (see Section 3.10.4).

The response to a Config NetKey Update message is a Config NetKey Status message.

Field	Size (octets)	Notes
NetKeyIndex	2	Index of the NetKey
NetKey	16	NetKey

Table 4.60: Config NetKey Update message parameters

The NetKeyIndex field is an index that shall identify the global NetKey Index of the NetKey. The NetKeyIndex field shall be encoded as defined in Section 4.3.1.1.

The NetKey field shall contain the NetKey.

4.3.2.33 Config NetKey Delete

The Config NetKey Delete is an acknowledged message used to delete a NetKey on a NetKey List from a node.



The response to a Config NetKey Delete message is a Config NetKey Status message.

Field	Size (octets)	Notes
NetKeyIndex	2	Index of the NetKey

Table 4.61: Config NetKey Delete message parameters

The NetKeyIndex field is an index that shall identify the global NetKey Index of the NetKey. The NetKeyIndex field shall be encoded as defined in Section 4.3.1.1.

4.3.2.34 Config NetKey Status

The Config NetKey Status is an unacknowledged message used to report the status of the operation on the NetKey List.

Field	Size (octets)	Notes
Status	1	Status Code for the requesting message
NetKeyIndex	2	Index of the NetKey

Table 4.62: Config NetKey Status message parameters

The Status field shall identify the Status Code for the last operation on the NetKey List. The allowed values for Status codes and their meanings are documented in Section 4.3.5. The Status Code shall be Success if the received request was redundant (add of an identical existing key, update of an identical updated key, or delete of a non-existent key), with no further action taken.

The NetKeyIndex field is an index that shall identify the global NetKey Index of the NetKey. The NetKeyIndex field shall be encoded as defined in Section 4.3.1.1.

4.3.2.35 Config NetKey Get

The Config NetKey Get is an acknowledged message used to report all NetKeys known to the node.

The response to a Config NetKey Get message is a Config NetKey List message.

There are no Parameters for this message.

4.3.2.36 Config NetKey List

The Config NetKey List is an unacknowledged message reporting all NetKeys known to the node.

Field	Size (octets)	Notes
NetKeyIndexes	variable	A list of NetKey Indexes known to the node

Table 4.63: Config NetKey List message parameters

The NetKeyIndexes field shall contain all NetKey Indexes that are known to the node. The NetKey Indexes shall be encoded as defined in Section 4.3.1.1.



4.3.2.37 Config AppKey Add

The Config AppKey Add is an acknowledged message used to add an AppKey to the AppKey List on a node and bind it to the NetKey identified by NetKeyIndex. The added AppKey can be used by the node only as a pair with the specified NetKey. The AppKey is used to authenticate and decrypt messages it receives, as well as authenticate and encrypt messages it sends.

The response to a Config AppKey Add message is a Config AppKey Status message.

Field	Size (octets)	Notes
NetKeyIndexAndAppKeyIndex	3	Index of the NetKey and index of the AppKey
AppKey	16	AppKey value

Table 4.64: Config AppKey Add message parameters

The NetKeyIndexAndAppKeyIndex field contains two indexes that shall identify the global NetKey Index of the NetKey and the global AppKey Index of the AppKey. These two indexes shall be encoded as defined in Section 4.3.1.1 using NetKey Index as first key index and AppKey Index as second key index.

The AppKey field shall contain the AppKey value identified by the AppKeyIndex.

4.3.2.38 Config AppKey Update

The Config AppKey Update is an acknowledged message used to update an AppKey value on the AppKey List on a node. The updated AppKey is used by the node to authenticate and decrypt messages it receives, as well as authenticate and encrypt messages it sends, as defined by the Key Refresh procedure (see Section 3.10.4).

The response to an Config AppKey Update message is an Config AppKey Status message.

Field	Size (octets)	Notes
NetKeyIndexAndAppKeyIndex	3	Index of the NetKey and index of the AppKey
AppKey	16	New AppKey value

Table 4.65: Config AppKey Update message parameters

The NetKeyIndexAndAppKeyIndex field contains two indexes that shall identify the global NetKey Index of the NetKey and the global AppKey Index of the AppKey. These two indexes shall be encoded as defined in Section 4.3.1.1 using NetKey Index as first key index and AppKey Index as second key index. The AppKeyIndex shall be bound to the NetKeyIndex.

The AppKey field shall contain the new value of the AppKey, identified by the AppKeyIndex.

4.3.2.39 Config AppKey Delete

The Config AppKey Delete is an acknowledged message used to delete an AppKey from the AppKey List on a node.



The response to a Config AppKey Delete message is a Config AppKey Status message.

Field	Size (octets)	Notes
NetKeyIndexAndAppKeyIndex	3	Index of the NetKey and index of the AppKey

Table 4.66: Config AppKey Delete message parameters

The NetKeyIndexAndAppKeyIndex field contains two indexes that shall identify the global NetKey Index of the NetKey and the global AppKey Index of the AppKey. These two indexes shall be encoded as defined in Section 4.3.1.1 using NetKey Index as first key index and AppKey Index as second key index.

4.3.2.40 Config AppKey Status

The Config AppKey Status is an unacknowledged message used to report a status for the requesting message, based on the NetKey Index identifying the NetKey on the NetKey List and on the AppKey Index identifying the AppKey on the AppKey List.

Field	Size (octets)	Notes
Status	1	Status Code for the requesting message
NetKeyIndexAndAppKeyIndex	3	Index of the NetKey and index of the AppKey

Table 4.67: Config AppKey Status message parameters

The Status field shall identify the Status Code for the last operation on the AppKey List. The allowed values for Status codes and their meanings are documented in Section 4.3.5. The Status Code shall be Success if the received request was redundant (add of an identical existing key, update of an identical updated key, or delete of a non-existent key), with no further action taken.

The NetKeyIndexAndAppKeyIndex field contains two indexes that shall identify the global NetKey Index of the NetKey and the global AppKey Index of the AppKey. These two indexes shall be encoded as defined in Section 4.3.1.1 using NetKey Index as first key index and AppKey Index as second key index.

4.3.2.41 Config AppKey Get

The AppKey Get is an acknowledged message used to report all AppKeys bound to the NetKey.

The response to a Config AppKey Get message is a Config AppKey List message.

Field	Size (octets)	Notes
NetKeyIndex	2	Index of the NetKey

Table 4.68: Config AppKey Get message parameters

The NetKeyIndex field is an index that shall identify the global NetKey Index of the NetKey. The NetKeyIndex field shall be encoded as defined in Section 4.3.1.1.

4.3.2.42 Config AppKey List

The Config AppKey List is an unacknowledged message reporting all AppKeys that are bound to the NetKey.

Field	Size (octets)	Notes
Status	1	Status Code for the requesting message
NetKeyIndex	2	NetKey Index of the NetKey that the AppKeys are bound to
AppKeyIndexes	variable	A list of AppKey indexes that are bound to the NetKey identified by NetKeyIndex

Table 4.69: Config AppKey List message parameters

The Status field shall identify the Status Code for the last operation on the AppKey of the NetKey. The allowed values for Status codes and their meanings are documented in Section 4.3.5.

The NetKeyIndex field is an index that shall identify the global NetKey Index of the NetKey to which the AppKeys are bound. The NetKeyIndex field shall be encoded as defined in Section 4.3.1.1.

The AppKeyIndexes field shall contain all AppKey indexes that are bound to the NetKey. The AppKey indexes shall be encoded as defined in Section 4.3.1.1.

4.3.2.43 Config Node Identity Get

The Config Node Identity Get is an acknowledged message used to get the current Node Identity state for a subnet (see Section 4.2.12).

The response to a Config Node Identity Get message is a Config Node Identity Status message.

Field	Size (octets)	Notes
NetKeyIndex	2	Index of the NetKey

Table 4.70: Config Node Identity Get message parameters

The NetKeyIndex field is an index that shall identify the global NetKey Index of the NetKey. The NetKeyIndex field shall be encoded as defined in Section 4.3.1.1.

4.3.2.44 Config Node Identity Set

The Config Node Identity Set is an acknowledged message used to set the current Node Identity state for a subnet (see Section 4.2.12).

The response to a Config Node Identity Set message is a Config Node Identity Status message.

Field	Size (octets)	Notes
NetKeyIndex	2	Index of the NetKey
Identity	1	New Node Identity state

Table 4.71: Config Node Identity Set message parameters

The NetKeyIndex field is an index that shall identify the global NetKey Index of the NetKey of the Node Identity state. The NetKeyIndex field shall be encoded as defined in Section 4.3.1.1.

The Identity field shall provide the new Node Identity state of the NetKey (see Section 4.2.12).

4.3.2.45 Config Node Identity Status

The Config Node Identity Status is an unacknowledged message used to report the current Node Identity state for a subnet (see Section 4.2.12).

Field	Size (octets)	Notes
Status	1	Status Code for the requesting message
NetKeyIndex	2	Index of the NetKey
Identity	1	Node Identity state

Table 4.72: Config Node Identity Status message parameters

The Status field shall identify the Status Code for the requesting message. The allowed values for Status codes and their meanings are documented in Section 4.3.5.

The NetKeyIndex field is an index that shall identify the global NetKey Index of the NetKey of the Node Identity state. The NetKeyIndex field shall be encoded as defined in Section 4.3.1.1.

The Identity field shall provide the current Node Identity state for a subnet (see Section 4.2.12).

4.3.2.46 Config Model App Bind

The Config Model App Bind is an acknowledged message used to bind an AppKey to a model.

The response to a Config Model App Bind message is a Config Model App Status message.

Field	Size (octets)	Notes
ElementAddress	2	Address of the element
AppKeyIndex	2	Index of the AppKey
ModelIdentifier	2 or 4	SIG Model ID or Vendor Model ID

Table 4.73: Config Model App Bind message parameters

The ElementAddress field is the unicast address of the element, all other address types are Prohibited.



The AppKeyIndex field is an index that shall identify the global AppKey Index of the AppKey. The AppKeyIndex field shall be encoded as defined in Section 4.3.1.1.

The ModelIdentifier field is either a SIG Model ID or a Vendor Model ID that shall identify the model within the element.

4.3.2.47 Config Model App Unbind

The Config Model App Unbind is an acknowledged message used to remove the binding between an AppKey and a model.

The response to a Config Model App Unbind message is a Config Model App Status message.

Field	Size (octets)	Notes
ElementAddress	2	Address of the element
AppKeyIndex	2	Index of the AppKey
ModelIdentifier	2 or 4	SIG Model ID or Vendor Model ID

Table 4.74: Config Model App Unbind message parameters

The ElementAddress field is the unicast address of the element, all other address types are Prohibited.

The AppKeyIndex field is an index that shall identify the global AppKey Index of the AppKey. The AppKeyIndex field shall be encoded as defined in Section 4.3.1.1.

The ModelIdentifier field is a SIG Model ID or a Vendor Model ID that shall identify the model within the element.

4.3.2.48 Config Model App Status

The Config Model App Status is an unacknowledged message used to report a status for the requesting message, based on the element address, the AppKeyIndex identifying the AppKey on the AppKey List, and the ModelIdentifier.

Field	Size (octets)	Notes
Status	1	Status Code for the requesting message
ElementAddress	2	Address of the element
AppKeyIndex	2	Index of the AppKey
ModelIdentifier	2 or 4	SIG Model ID or Vendor Model ID

Table 4.75: Config Model App Status message parameters

The Status field shall identify the Status Code for the requesting message. The allowed values for Status codes and their meanings are documented in Section 4.3.5. The Status Code shall be Success if the received request was redundant (bind request of existing binding, or unbind of a non-existing binding), with no further action taken.



The ElementAddress field is the unicast address of the element, all other address types are Prohibited.

The AppKeyIndex field is an index that shall identify the global AppKey Index of the AppKey. The AppKeyIndex field shall be encoded as defined in Section 4.3.1.1.

The ModelIdentifier field is a SIG Model ID or a Vendor Model ID that shall identify the model within the element.

4.3.2.49 Config SIG Model App Get

The Config SIG Model App Get is an acknowledged message used to request report of all AppKeys bound to the SIG Model.

The response to a Config SIG Model App Get message is a Config SIG Model App List message.

Field	Size (octets)	Notes
ElementAddress	2	Address of the element
ModelIdentifier	2	SIG Model ID

Table 4.76: Config SIG Model App Get message parameters

The ElementAddress field is the unicast address of the element, all other address types are Prohibited.

The ModelIdentifier field is a SIG Model ID that shall identify the model within the element.

4.3.2.50 Config SIG Model App List

The Config SIG Model App List is an unacknowledged message used to report all AppKeys bound to the SIG Model.

Field	Size (octets)	Notes
Status	1	Status Code for the requesting message
ElementAddress	2	Address of the element
ModelIdentifier	2	SIG Model ID
AppKeyIndexes	Variable	All AppKey indexes bound to the Model

Table 4.77: Config SIG Model App List message parameters

The Status field shall identify the Status Code for the requesting message. The allowed values for Status codes and their meanings are documented in Section 4.3.5.

The ElementAddress field is the unicast address of the element, all other address types are Prohibited.

The ModelIdentifier field is a SIG Model ID that shall identify the SIG model within the element.

The AppKeyIndexes field shall contain all AppKey indexes that are bound to an instance of a model. The AppKey indexes shall be encoded as defined in Section 4.3.1.1.



4.3.2.51 Config Vendor Model App Get

The Config Vendor Model App Get is an acknowledged message used to request report of all AppKeys bound to the model. This message is only for Vendor Models.

The response to a Config Vendor Model App Get message is a Config Vendor Model App List message.

Field	Size (octets)	Notes
ElementAddress	2	Address of the element
ModelIdentifier	4	Vendor Model ID

Table 4.78: Config Vendor Model App Get message parameters

The ElementAddress field is the unicast address of the element, all other address types are Prohibited.

The ModelIdentifier field is a Vendor Model ID that shall identify the model within the element.

4.3.2.52 Config Vendor Model App List

The Config Vendor Model App List is an unacknowledged message used to report indexes of all AppKeys bound to the model. This message is only for Vendor Models.

Field	Size (octets)	Notes
Status	1	Status Code for the requesting message
ElementAddress	2	Address of the element
ModelIdentifier	4	Vendor Model ID
AppKeyIndexes	variable	Indexes of all AppKeys bound to the model

Table 4.79: Config Vendor Model App List message parameters

The Status field shall identify the Status Code for the requesting message. The allowed values for Status codes and their meanings are documented in Section 4.3.5.

The ElementAddress field is the unicast address of the element, all other address types are Prohibited.

The ModelIdentifier field is a Vendor Model ID that shall identify the model within the element.

The AppKeyIndexes field shall contain indexes of all AppKeys that are bound to an instance of a model. The AppKey indexes shall be encoded as defined in Section 4.3.1.1.

4.3.2.53 Config Node Reset

The Config Node Reset is an acknowledged message used to reset a node (other than a Provisioner) and remove it from the network.

The response to a Config Node Reset message is a Config Node Reset Status message.

There are no Parameters for this message.



4.3.2.54 Config Node Reset Status

The Config Node Reset Status is an unacknowledged message used to acknowledge that an element has received a Config Node Reset message.

There are no Parameters for this message.

4.3.2.55 Config Friend Get

The Config Friend Get is an acknowledged message used to get the current Friend state of a node (see Section 4.2.13).

The response to a Config Friend Get message is a Config Friend Status message.

There are no Parameters for this message.

4.3.2.56 Config Friend Set

The Config Friend Set is an acknowledged message used to set the Friend state of a node (see Section 4.2.13).

The response to a Config Friend Set message is a Config Friend Status message.

Field	Size (octets)	Notes
Friend	1	New Friend state

Table 4.80: Config Friend Set message parameters

The Friend field shall provide the new Friend state of the node (see Section 4.2.13).

4.3.2.57 Config Friend Status

The Config Friend Status is an unacknowledged message used to report the current Friend state of a node (see Section 4.2.13).

Field	Size (octets)	Notes
Friend	1	Friend state

Table 4.81: Config Friend Status message parameters

The Friend field shall provide the current Friend state of the node (see Section 4.2.13).

4.3.2.58 Config Key Refresh Phase Get

The Config Key Refresh Phase Get is an acknowledged message used to get the current Key Refresh Phase state of the identified network key.

The response to a Config Key Refresh Phase Get message is a Config Key Refresh Phase Status message.



Parameter	Size (octets)	Notes
NetKeyIndex	2	NetKey Index

Table 4.82: Config Key Refresh Phase Get message parameters

The NetKeyIndex field shall identify the global NetKey Index of the NetKey. The NetKeyIndex field shall be encoded as defined in Section 4.3.1.1.

4.3.2.59 Config Key Refresh Phase Set

The Config Key Refresh Phase Set is an acknowledged message used to set the Key Refresh Phase state of the identified network key (see Section 4.2.14).

The response to a Config Key Refresh Phase Set message is a Config Key Refresh Phase Status message.

Parameter	Size (octets)	Notes
NetKeyIndex	2	NetKey Index
Transition	1	New Key Refresh Phase Transition

Table 4.83: Config Key Refresh Phase Set message parameters

The NetKeyIndex field shall identify the global NetKey Index of the NetKey. The NetKeyIndex field shall be encoded as defined in Section 4.3.1.1.

The Transition field shall identify the Key Refresh Phase Transitions (see Section 4.2.14, Table 4.18) allowed for each given starting state. All other transition values are Prohibited.

4.3.2.60 Config Key Refresh Phase Status

The Config Key Refresh Phase Status is an unacknowledged message used to report the current Key Refresh Phase state of the identified network key (see Section 4.2.14).

Parameters	Size (octets)	Notes
Status	1	Status Code for the requesting message
NetKeyIndex	2	NetKey Index
Phase	1	Key Refresh Phase State

Table 4.84: Config Key Refresh Phase Status message parameters

The Status field shall identify the Status Code for the requesting message. The allowed values for Status codes and their meanings are documented in Section 4.3.5. The Status Code shall be Success if the received request was redundant (the requested phase transition has already occurred), with no further action taken.

The NetKeyIndex field shall identify the global NetKey Index of the NetKey. The NetKeyIndex field shall be encoded as defined in Section 4.3.1.1.

The Phase field shall identify the Key Refresh Phase state for the node, as defined in Key Refresh Phase (see Section 4.2.14).

4.3.2.61 Config Heartbeat Publication Get

The Config Heartbeat Publication Get is an acknowledged message used to get the current Heartbeat Publication state of an element (see Section 4.2.17).

The response to a Config Heartbeat Publication Get message is a Config Heartbeat Publication Status message.

The message has no parameters.

4.3.2.62 Config Heartbeat Publication Set

The Config Heartbeat Publication Set is an acknowledged message used to set the current Heartbeat Publication state of an element (see Section 4.2.17).

The response to a Config Heartbeat Publication Set message is a Config Heartbeat Publication Status message.

Parameters	Size (octets)	Notes
Destination	2	Destination address for Heartbeat messages
CountLog	1	Number of Heartbeat messages to be sent
PeriodLog	1	Period for sending Heartbeat messages
TTL	1	TTL to be used when sending Heartbeat messages
Features	2	Bit field indicating features that trigger Heartbeat messages when changed
NetKeyIndex	2	NetKey Index

Table 4.85: Config Heartbeat Publication Set message parameters

The Destination field shall identify the Heartbeat Publication Destination state (see Section 4.2.17.1).

The CountLog field shall identify the Heartbeat Publication Count Log representation of the Heartbeat Publication Count state (see Section 4.2.17.2).

The PeriodLog field shall identify the Heartbeat Publication Period Log state (see Section 4.2.17.3).

The TTL field shall identify the Heartbeat Publication TTL state (see Section 4.2.17.4).

The Features field shall identify the Heartbeat Publication Features state (see Section 4.2.17.5).

The NetKeyIndex field shall identify the global NetKey Index of the NetKey. The NetKeyIndex field shall be encoded as defined in Section 4.3.1.1.

4.3.2.63 Config Heartbeat Publication Status

The Config Heartbeat Publication Status is an unacknowledged message used to report the Heartbeat Publication state of a node (see Section 4.2.17).

Parameters	Size (octets)	Notes
Status	1	Status Code for the requesting message
Destination	2	Destination address for Heartbeat messages
CountLog	1	Number of Heartbeat messages remaining to be sent
PeriodLog	1	Period for sending Heartbeat messages
TTL	1	TTL to be used when sending Heartbeat messages
Features	2	Bit field indicating features that trigger Heartbeat messages when changed
NetKeyIndex	2	NetKey Index

Table 4.86: Config Heartbeat Publication Status message parameters

The Status field shall identify the Status Code for the requesting message. The allowed values for Status codes and their meanings are documented in Section 4.3.5.

The Destination field shall identify the Heartbeat Publication Destination state (see Section 4.2.17.1).

The CountLog field shall identify the Heartbeat Publication Count Log representation of the Heartbeat Publication Count state (see Section 4.2.17.2).

The PeriodLog field shall identify the Heartbeat Publication Period Log state (see Section 4.2.17.3).

The TTL field shall identify the Heartbeat Publication TTL state (see Section 4.2.17.4).

The Features field shall identify the Heartbeat Publication Features state (see Section 4.2.17.5).

The NetKeyIndex field shall identify the global NetKey Index of the NetKey used to publish heartbeats. The NetKeyIndex field shall be encoded as defined in Section 4.3.1.1.

4.3.2.64 Config Heartbeat Subscription Get

The Config Heartbeat Subscription Get is an acknowledged message used to get the current Heartbeat Subscription state of an element (see Section 4.2.18).

The response to a Config Heartbeat Subscription Get message is a Config Heartbeat Subscription Status message.

The message has no parameters.



4.3.2.65 Config Heartbeat Subscription Set

The Config Heartbeat Subscription Set is an acknowledged message used to set the current Heartbeat Subscription state of an element (see Section 4.2.18).

The response to a Config Heartbeat Subscription Set message is a Config Heartbeat Subscription Status message.

Parameters	Size (octets)	Notes
Source	2	Source address for Heartbeat messages
Destination	2	Destination address for Heartbeat messages
PeriodLog	1	Period for receiving Heartbeat messages

Table 4.87: Config Heartbeat Subscription Set message parameters

The Source field shall identify the Heartbeat Subscription Source state (see Section 4.2.18.1).

The Destination field shall identify the Heartbeat Subscription Destination state (see Section 4.2.18.2)

The PeriodLog field shall identify the Heartbeat Subscription Period state (see Section 4.2.18.4).

4.3.2.66 Config Heartbeat Subscription Status

The Config Heartbeat Subscription Status is an unacknowledged message used to report the Heartbeat Subscription state of a node (see Section 4.2.18).

Parameters	Size (octets)	Notes
Status	1	Status Code for the requesting message
Source	2	Source address for Heartbeat messages
Destination	2	Destination address for Heartbeat messages
PeriodLog	1	Remaining Period for processing Heartbeat messages
CountLog	1	Number of Heartbeat messages received
MinHops	1	Minimum hops when receiving Heartbeat messages
MaxHops	1	Maximum hops when receiving Heartbeat messages

Table 4.88: Config Heartbeat Subscription Status message parameters

The Status field shall identify the Status Code for the requesting message. The allowed values for Status codes and their meanings are documented in Section 4.3.5.

The Source field shall identify the Heartbeat Subscription Source state (see Section 4.2.18.1).

The Destination field shall identify the Heartbeat Subscription Destination state (see Section 4.2.18.2).

The PeriodLog field shall identify the Heartbeat Subscription Period Log state (see Section 4.2.18.4).

The CountLog field shall identify the Heartbeat Subscription Count Log representation of the Heartbeat Publication Count state (see Section 4.2.18.3).

The MinHops field shall identify the Heartbeat Subscription Min Hops state (see Section 4.2.18.5).

The MaxHops field shall identify the Heartbeat Subscription Max Hops state (see Section 4.2.18.6).

4.3.2.67 Config Low Power Node PollTimeout Get

The Config Low Power Node PollTimeout Get is an acknowledged message used to get the current value of PollTimeout timer of the Low Power node within a Friend node (see Section 3.6.6.1). The message is sent to a Friend node that has claimed to be handling messages by sending ACKs On Behalf Of (OBO) the indicated Low Power node. This message should only be sent to a node that has the Friend feature supported and enabled.

The response to a Config Low Power Node PollTimeout Get message is a Config Low Power Node PollTimeout Status message.

Field	Size (octets)	Notes
LPNAddress	2	The unicast address of the Low Power node

Table 4.89: Config Low Power Node PollTimeout Get message parameters

The LPNAddress field shall contain the primary unicast address of the Low Power node within a Friend node.

4.3.2.68 Config Low Power Node PollTimeout Status

The Config Low Power Node PollTimeout Status is an unacknowledged message used to report the current value of the PollTimeout timer of the Low Power node within a Friend node.

Field	Size (octets)	Notes
LPNAddress	2	The unicast address of the Low Power node
PollTimeout	3	The current value of the PollTimeout timer of the Low Power node

Table 4.90: Config Low Power Node PollTimeout Status message parameters

The LPNAddress field shall contain the primary unicast address of the Low Power node.

The PollTimeout field shall contain the current value of the PollTimeout timer of the Low Power node within a Friend node, or 0x000000 if the node is not a Friend node for the Low Power node identified by LPNAddress.

4.3.2.69 Config Network Transmit Get

The Config Network Transmit Get is an acknowledged message used to get the current Network Transmit state of a node (see Section 4.2.19).

The response to a Config Network Transmit Get message is a Config Network Transmit Status message.



There are no Parameters for this message.

4.3.2.70 Config Network Transmit Set

The Config Network Transmit Set is an acknowledged message used to set the Network Transmit state of a node (see Section 4.2.19).

The response to a Config Network Transmit Set message is a Config Network Transmit Status message.

Field	Size (bits)	Notes
NetworkTransmitCount	3	Number of transmissions for each Network PDU originating from the node
NetworkTransmitIntervalSteps	5	Number of 10-millisecond steps between transmissions

Table 4.91: Config Network Transmit Set message parameters

The NetworkTransmitCount field shall contain a new value for the Network Transmit Count state of a node (see Section 4.2.19.1).

The NetworkTransmitIntervalSteps field shall contain a new value for the Network Transmit Interval Steps state of a node (see Section 4.2.19.2).

4.3.2.71 Config Network Transmit Status

The Config Network Transmit Status is an unacknowledged message used to report the current Network Transmit state of a node (see Section 4.2.19).

Field	Size (bits)	Notes
NetworkTransmitCount	3	Number of transmissions for each Network PDU originating from the node
NetworkTransmitIntervalSteps	5	Number of 10-millisecond steps between transmissions

Table 4.92: Config Network Transmit Set message parameters

The NetworkTransmitCount field shall contain a new value for the Network Transmit Count state of a node (see Section 4.2.19.1).

The NetworkTransmitIntervalSteps field shall contain a new value for the Network Transmit Interval Steps state of a node (see Section 4.2.19.2).

4.3.3 Health messages

Health messages are used to monitor states that determine the physical condition of a node.

Health messages shall be encrypted and authenticated using an AppKey.

4.3.3.1 Health Current Status

The Health Current Status is an unacknowledged message used to report the Current Health state of an element (see Section 4.2.15.1). The message may contain several Fault fields, depending on the number of concurrently present fault conditions. If no Fault fields are present, it means no fault condition exists on an element.

The message uses a single-octet opcode to maximize the size of the FaultArray.

Parameters	Size (octets)	Notes
Test ID	1	Identifier of a most recently performed test
Company ID	2	16-bit Bluetooth assigned Company Identifier
FaultArray	N	The FaultArray field contains a sequence of 1-octet fault values

Table 4.93: Health Current Status message parameters

The Test ID field identifies a most recently performed test by the element.

The Company ID field is a Bluetooth assigned Company Identifier [6]. It shall be used to resolve vendor specific fault codes as specified in Table 4.21.

The FaultArray field contains a sequence of fault values, as specified in Table 4.21.

4.3.3.2 Health Fault Get

The Health Fault Get is an acknowledged message used to get the current Registered Fault state identified by Company ID of an element (see Section 4.2.15.2).

The response to a Health Fault Get message is a Health Fault Status message.

Parameters	Size (octets)	Notes
Company ID	2	16-bit Bluetooth assigned Company Identifier

Table 4.94: Health Fault Get message parameters

The Company ID field is a Bluetooth assigned Company identifier [6]. It shall be used to resolve specific fault codes as specified in Table 4.21.

4.3.3.3 Health Fault Clear Unacknowledged

The Health Fault Clear Unacknowledged is an unacknowledged message used to clear the current Registered Fault state identified by Company ID of an element (see Section 4.2.15.2).



Parameters	Size (octets)	Notes
Company ID	2	16-bit Bluetooth assigned Company Identifier

Table 4.95: Health Fault Clear Unacknowledged message parameters

The Company ID field is a Bluetooth assigned Company identifier [6]. It shall be used to resolve specific fault codes as specified in Table 4.21.

4.3.3.4 Health Fault Clear

The Health Fault Clear is an acknowledged message used to clear the current Registered Fault state identified by Company ID of an element (see Section 4.2.15.2).

The response to a Health Fault Clear message is a Health Fault Status message.

Parameters	Size (octets)	Notes
Company ID	2	16-bit Bluetooth assigned Company Identifier

Table 4.96: Health Fault Clear message parameters

The Company ID field is a Bluetooth assigned Company identifier [6]. It shall be used to resolve specific fault codes as specified in Table 4.21

4.3.3.5 Health Fault Test

The Health Fault Test is an acknowledged message used to invoke a self-test procedure of an element. The procedure is implementation specific and may result in changing the Health Fault state of an element (see Section 4.2.15).

The response to a Health Fault Test message is a Health Fault Status message.

Parameters	Size (octets)	Notes
Test ID	1	Identifier of a specific test to be performed
Company ID	2	16-bit Bluetooth assigned Company Identifier

Table 4.97: Health Fault Test message parameters

The Test ID field identifies a test the element should perform.

The Company ID field is a Bluetooth assigned Company Identifier [6]. It shall be used to resolve vendor specific fault codes as specified in Table 4.21.

4.3.3.6 Health Fault Test Unacknowledged

The Health Fault Test Unacknowledged is an unacknowledged message used to invoke a self-test procedure of an element. The procedure is implementation specific and may result in changing the Health Fault state of an element (see Section 4.2.15).



Parameters	Size (octets)	Notes
Test ID	1	Identifier of a specific test to be performed
Company ID	2	16-bit Bluetooth assigned Company Identifier

Table 4.98: Health Fault Test Unacknowledged message parameters

The Test ID field identifies a test the element should perform.

The Company ID field is a Bluetooth assigned Company Identifier [6]. It shall be used to resolve vendor specific fault codes as specified in Table 4.21.

4.3.3.7 Health Fault Status

The Health Fault Status is an unacknowledged message used to report the current Registered Fault state of an element (see Section 4.2.15.2). The message may contain several Fault fields, depending on the number of concurrently present fault conditions. If no Fault fields are present, it means no registered fault condition exists on an element.

The message uses a single-octet opcode to maximize the size of the FaultArray.

Parameters	Size (octets)	Notes
Test ID	1	Identifier of a most recently performed test
Company ID	2	16-bit Bluetooth assigned Company Identifier
FaultArray	N	The FaultArray field contains a sequence of 1-octet fault values

Table 4.99: Health Fault Status message parameters

The Test ID field identifies a most recently performed test by the element.

The Company ID field is a Bluetooth assigned Company Identifier (<https://www.bluetooth.com/specifications/assigned-numbers/company-identifiers>). It shall be used to resolve vendor specific fault codes as specified in Table 4.22.

The FaultArray field contains a sequence of fault values, as specified in Table 4.22.

4.3.3.8 Health Period Get

The Health Period Get is an acknowledged message used to get the current Health Fast Period Divisor state of an element (see Section 4.2.16).

The response to a Health Period Get message is a Health Period Status message.

There are no parameters for this message.

4.3.3.9 Health Period Set Unacknowledged

The Health Period Set Unacknowledged is an unacknowledged message used to set the current Health Fast Period Divisor state of an element (see Section 4.2.16).

Parameters	Size (octets)	Notes
FastPeriodDivisor	1	Divider for the Publish Period. Modified Publish Period is used for sending Current Health Status messages when there are active faults to communicate

Table 4.100: Health Period Set Unacknowledged message parameters

The FastPeriodDivisor field shall identify the Health Fast Period Divisor state for the element (see Section 4.2.16).

4.3.3.10 Health Period Set

The Health Period Set is an acknowledged message used to set the current Health Fast Period Divisor state of an element (see Section 4.2.16).

The response to a Health Period Set message is a Health Period Status message.

Parameters	Size (octets)	Notes
FastPeriodDivisor	1	Divider for the Publish Period. Modified Publish Period is used for sending Current Health Status messages when there are active faults to communicate

Table 4.101: Health Period Set message parameters

The FastPeriodDivisor field shall identify the Health Fast Period Divisor state for the element (see Section 4.2.16).

4.3.3.11 Health Period Status

The Health Period Status is an unacknowledged message used to report the Health Fast Period Divisor state of an element (see Section 4.2.16).

Parameters	Size (octets)	Notes
FastPeriodDivisor	1	Divider for the Publish Period. Modified Publish Period is used for sending Current Health Status messages when there are active faults to communicate

Table 4.102: Health Period Status message parameters

The FastPeriodDivisor field shall identify the Health Fast Period Divisor state for the element (see Section 4.2.16).



4.3.3.12 Health Attention Get

The Health Attention Get is an acknowledged message used to get the current Attention Timer state of an element (see Section 4.2.9).

The response to a Health Attention Get message is an Attention Status message.

There are no Parameters for this message.

4.3.3.13 Health Attention Set

The Health Attention Set is an acknowledged message used to set the Attention Timer state of an element (see Section 4.2.9).

The response to a Health Attention Set message is a Health Attention Status message.

Field	Size (octets)	Notes
Attention	1	Value of the Attention Timer state

Table 4.103: Health Attention Set message parameters

The Attention field shall identify the new Attention Timer state of an element (see Section 4.2.9).

4.3.3.14 Health Attention Set Unacknowledged

The Health Attention Set Unacknowledged is an unacknowledged message used to set the Attention Timer state of an element (see Section 4.2.9).

Field	Size (octets)	Notes
Attention	1	Value of the Attention Timer state

Table 4.104: Health Attention Set Unacknowledged message parameters

The Attention field shall identify the new Attention Timer state of an element (see Section 4.2.9).

4.3.3.15 Health Attention Status

The Health Attention Status is an unacknowledged message used to report the current Attention Timer state of an element (see Section 4.2.9).

Field	Size (octets)	Notes
Attention	1	Value of the Attention Timer state

Table 4.105: Attention Status message parameters

The Attention field shall identify the current Attention Timer state of the node (see Section 4.2.9).

4.3.4 Messages summary

4.3.4.1 Alphabetical summary of opcodes

Message Name	Opcode
Config AppKey Add	0x00
Config AppKey Delete	0x80 0x00
Config AppKey Get	0x80 0x01
Config AppKey List	0x80 0x02
Config AppKey Status	0x80 0x03
Config AppKey Update	0x01
Config Beacon Get	0x80 0x09
Config Beacon Set	0x80 0x0A
Config Beacon Status	0x80 0x0B
Config Composition Data Get	0x80 0x08
Config Composition Data Status	0x02
Config Config Model Publication Set	0x03
Config Default TTL Get	0x80 0x0C
Config Default TTL Set	0x80 0x0D
Config Default TTL Status	0x80 0x0E
Config Friend Get	0x80 0x0F
Config Friend Set	0x80 0x10
Config Friend Status	0x80 0x11
Config GATT Proxy Get	0x80 0x12
Config GATT Proxy Set	0x80 0x13
Config GATT Proxy Status	0x80 0x14
Config Heartbeat Publication Get	0x80 0x38
Config Heartbeat Publication Set	0x80 0x39
Config Heartbeat Publication Status	0x06
Config Heartbeat Subscription Get	0x80 0x3A
Config Heartbeat Subscription Set	0x80 0x3B
Config Heartbeat Subscription Status	0x80 0x3C
Config Key Refresh Phase Get	0x80 0x15
Config Key Refresh Phase Set	0x80 0x16
Config Key Refresh Phase Status	0x80 0x17
Config Low Power Node PollTimeout Get	0x80 0x2D
Config Low Power Node PollTimeout Status	0x80 0x2E



Message Name	Opcode
Config Model App Bind	0x80 0x3D
Config Model App Status	0x80 0x3E
Config Model App Unbind	0x80 0x3F
Config Model Publication Get	0x80 0x18
Config Model Publication Status	0x80 0x19
Config Model Publication Virtual Address Set	0x80 0x1A
Config Model Subscription Add	0x80 0x1B
Config Model Subscription Delete	0x80 0x1C
Config Model Subscription Delete All	0x80 0x1D
Config Model Subscription Overwrite	0x80 0x1E
Config Model Subscription Status	0x80 0x1F
Config Model Subscription Virtual Address Add	0x80 0x20
Config Model Subscription Virtual Address Delete	0x80 0x21
Config Model Subscription Virtual Address Overwrite	0x80 0x22
Config NetKey Add	0x80 0x40
Config NetKey Delete	0x80 0x41
Config NetKey Get	0x80 0x42
Config NetKey List	0x80 0x43
Config NetKey Status	0x80 0x44
Config NetKey Update	0x80 0x45
Config Network Transmit Get	0x80 0x23
Config Network Transmit Set	0x80 0x24
Config Network Transmit Status	0x80 0x25
Config Node Identity Get	0x80 0x46
Config Node Identity Set	0x80 0x47
Config Node Identity Status	0x80 0x48
Config Node Reset	0x80 0x49
Config Node Reset Status	0x80 0x4A
Config Relay Get	0x80 0x26
Config Relay Set	0x80 0x27
Config Relay Status	0x80 0x28
Config SIG Model App Get	0x80 0x4B
Config SIG Model App List	0x80 0x4C
Config SIG Model Subscription Get	0x80 0x29



Message Name	Opcode
Config SIG Model Subscription List	0x80 0x2A
Config Vendor Model App Get	0x80 0x4D
Config Vendor Model App List	0x80 0x4E
Config Vendor Model Subscription Get	0x80 0x2B
Config Vendor Model Subscription List	0x80 0x2C
Health Attention Get	0x80 0x04
Health Attention Set	0x80 0x05
Health Attention Set Unacknowledged	0x80 0x06
Health Attention Status	0x80 0x07
Health Current Status	0x04
Health Fault Clear	0x80 0x2F
Health Fault Clear Unacknowledged	0x80 0x30
Health Fault Get	0x80 0x31
Health Fault Status	0x05
Health Fault Test	0x80 0x32
Health Fault Test Unacknowledged	0x80 0x33
Health Period Get	0x80 0x34
Health Period Set	0x80 0x35
Health Period Set Unacknowledged	0x80 0x36
Health Period Status	0x80 0x37

Table 4.106: Alphabetical summary of opcodes

4.3.4.2 Numerical summary of opcodes

Message Name	Opcode
Config AppKey Add	0x00
Config AppKey Update	0x01
Config Composition Data Status	0x02
Config Config Model Publication Set	0x03
Health Current Status	0x04
Health Fault Status	0x05
Config Heartbeat Publication Status	0x06
Config AppKey Delete	0x80 0x00
Config AppKey Get	0x80 0x01
Config AppKey List	0x80 0x02
Config AppKey Status	0x80 0x03



Message Name	Opcode
Health Attention Get	0x80 0x04
Health Attention Set	0x80 0x05
Health Attention Set Unacknowledged	0x80 0x06
Health Attention Status	0x80 0x07
Config Composition Data Get	0x80 0x08
Config Beacon Get	0x80 0x09
Config Beacon Set	0x80 0x0A
Config Beacon Status	0x80 0x0B
Config Default TTL Get	0x80 0x0C
Config Default TTL Set	0x80 0x0D
Config Default TTL Status	0x80 0x0E
Config Friend Get	0x80 0x0F
Config Friend Set	0x80 0x10
Config Friend Status	0x80 0x11
Config GATT Proxy Get	0x80 0x12
Config GATT Proxy Set	0x80 0x13
Config GATT Proxy Status	0x80 0x14
Config Key Refresh Phase Get	0x80 0x15
Config Key Refresh Phase Set	0x80 0x16
Config Key Refresh Phase Status	0x80 0x17
Config Model Publication Get	0x80 0x18
Config Model Publication Status	0x80 0x19
Config Model Publication Virtual Address Set	0x80 0x1A
Config Model Subscription Add	0x80 0x1B
Config Model Subscription Delete	0x80 0x1C
Config Model Subscription Delete All	0x80 0x1D
Config Model Subscription Overwrite	0x80 0x1E
Config Model Subscription Status	0x80 0x1F
Config Model Subscription Virtual Address Add	0x80 0x20
Config Model Subscription Virtual Address Delete	0x80 0x21
Config Model Subscription Virtual Address Overwrite	0x80 0x22
Config Network Transmit Get	0x80 0x23
Config Network Transmit Set	0x80 0x24
Config Network Transmit Status	0x80 0x25



Message Name	Opcode
Config Relay Get	0x80 0x26
Config Relay Set	0x80 0x27
Config Relay Status	0x80 0x28
Config SIG Model Subscription Get	0x80 0x29
Config SIG Model Subscription List	0x80 0x2A
Config Vendor Model Subscription Get	0x80 0x2B
Config Vendor Model Subscription List	0x80 0x2C
Config Low Power Node PollTimeout Get	0x80 0x2D
Config Low Power Node PollTimeout Status	0x80 0x2E
Health Fault Clear	0x80 0x2F
Health Fault Clear Unacknowledged	0x80 0x30
Health Fault Get	0x80 0x31
Health Fault Test	0x80 0x32
Health Fault Test Unacknowledged	0x80 0x33
Health Period Get	0x80 0x34
Health Period Set	0x80 0x35
Health Period Set Unacknowledged	0x80 0x36
Health Period Status	0x80 0x37
Config Heartbeat Publication Get	0x80 0x38
Config Heartbeat Publication Set	0x80 0x39
Config Heartbeat Subscription Get	0x80 0x3A
Config Heartbeat Subscription Set	0x80 0x3B
Config Heartbeat Subscription Status	0x80 0x3C
Config Model App Bind	0x80 0x3D
Config Model App Status	0x80 0x3E
Config Model App Unbind	0x80 0x3F
Config NetKey Add	0x80 0x40
Config NetKey Delete	0x80 0x41
Config NetKey Get	0x80 0x42
Config NetKey List	0x80 0x43
Config NetKey Status	0x80 0x44
Config NetKey Update	0x80 0x45
Config Node Identity Get	0x80 0x46
Config Node Identity Set	0x80 0x47



Message Name	Opcode
Config Node Identity Status	0x80 0x48
Config Node Reset	0x80 0x49
Config Node Reset Status	0x80 0x4A
Config SIG Model App Get	0x80 0x4B
Config SIG Model App List	0x80 0x4C
Config Vendor Model App Get	0x80 0x4D
Config Vendor Model App List	0x80 0x4E

Table 4.107: Numerical summary of opcodes

4.3.5 Summary of status codes

Table 4.108 defines status codes for messages that contain a Status parameter. Status messages are sent only in response to properly formatted messages (see Section 3.7.4.4).

Status Code	Status Code Name
0x00	Success
0x01	Invalid Address
0x02	Invalid Model
0x03	Invalid AppKey Index
0x04	Invalid NetKey Index
0x05	Insufficient Resources
0x06	Key Index Already Stored
0x07	Invalid Publish Parameters
0x08	Not a Subscribe Model
0x09	Storage Failure
0x0A	Feature Not Supported
0x0B	Cannot Update
0x0C	Cannot Remove
0x0D	Cannot Bind
0x0E	Temporarily Unable to Change State
0x0F	Cannot Set
0x10	Unspecified Error
0x11	Invalid Binding
0x12-0xFF	RFU

Table 4.108: Summary of status codes



4.4 Model definitions

This section defines models used throughout this specification.

Model definitions that are not required as part of this specification are defined in the Mesh Model specification [11] and follow the same format and architecture as mesh model definitions.

4.4.1 Configuration Server model

4.4.1.1 Description

The Configuration Server is a root model (i.e., it does not extend any other models).

This model is used to represent a mesh network configuration of a device.

The model shall be supported by a primary element and shall not be supported by any secondary elements. The application-layer security on the Configuration Server model shall use the device key established during provisioning.

The model defines the state instances as shown in [Table 4.109](#) below:

Configuration Server States		Bound States		
State	Instance	Model	State	Instance
Secure Network Beacon	Primary	-	-	-
Composition Data	Primary	-	-	-
Default TTL	Primary	-	-	-
GATT Proxy	Primary	Configuration Server	Node Identity	Primary
Friend	Primary	-	-	-
Relay	Primary	-	-	-
Model Publication	Primary	-	-	-
Subscription List	Primary	-	-	-
NetKey List	Primary	-	-	-
AppKey List	Primary	-	-	-
Model to AppKey List	Primary	-	-	-
Node Identity	Primary	-	-	-
Key Refresh Phase	Primary	-	-	-
Heartbeat Publish	Primary	-	-	-
Heartbeat Subscription	Primary	-	-	-
Network Transmit	Primary	-	-	-
Relay Retransmit	Primary	-	-	-

Table 4.109: Configuration Server states and bindings

The structure of elements, states, and messages covered by this model is defined below in [Table 4.110](#):



Element	SIG Model ID	States	Messages	Rx	Tx
Primary	0x0000	Secure Network Beacon (see Section 4.2.10)	Config Beacon Get	M	
			Config Beacon Set	M	
			Config Beacon Status		M
		Composition Data (see Section 4.2.1)	Config Composition Data Get	M	
			Config Composition Data Status		M
		Default TTL (see Section 4.2.7)	Config Default TTL Get	M	
			Config Default TTL Set	M	
			Config Default TTL Status		M
		GATT Proxy (see Section 4.2.11)	Config GATT Proxy Get	M	
			Config GATT Proxy Set	M	
			Config GATT Proxy Status		M
		Friend (see Section 4.2.13)	Config Friend Get	M	
			Config Friend Set	M	
			Config Friend Status		M
		Relay (see Section 4.2.8) and Relay Retransmit (see Section 4.2.20)	Config Relay Get	M	
			Config Relay Set	M	
			Config Relay Status		M
		Model Publication (see Section 4.2.2)	Config Model Publication Get	M	
			Config Model Publication Set	M	
			Config Model Publication Virtual Address Set	M	
			Config Model Publication Status		M
		Subscription List (see Section 4.2.3)	Config Model Subscription Add	M	
			Config Model Subscription Virtual Address Add	M	
			Config Model Subscription Delete	M	
			Config Model Subscription Virtual Address Delete	M	
			Config Model Subscription Virtual Address Overwrite	M	
			Config Model Subscription Overwrite	M	
			Config Model Subscription Delete All	M	

Element	SIG Model ID	States	Messages	Rx	Tx
			Config Model Subscription Status		M
			Config SIG Model Subscription Get	M	
			Config SIG Model Subscription List		M
			Config Vendor Model Subscription Get	M	
			Config Vendor Model Subscription List		M
		NetKey List (see Section 4.2.4)	Config NetKey Add	M	
			Config NetKey Update	M	
			Config NetKey Delete	M	
			Config NetKey Status		M
			Config NetKey Get	M	
			Config NetKey List		M
		AppKey List (see Section 4.2.5)	Config AppKey Add	M	
			Config AppKey Update	M	
			Config AppKey Delete	M	
			Config AppKey Status		M
			Config AppKey Get	M	
			Config AppKey List		M
		Model to AppKey List (see Section 4.2.6)	Config Model App Bind	M	
			Config Model App Unbind	M	
			Config Model App Status		M
			Config SIG Model App Get	M	
			Config SIG Model App List		M
			Config Vendor Model App Get	M	
			Config Vendor Model App List		M
		Node Identity (see Section 4.2.12)	Config Node Identity Get	M	
			Config Node Identity Set	M	
			Config Node Identity Status		M
		N/A	Config Node Reset	M	
			Config Node Reset Status		M
		Key Refresh Phase (see Section 4.2.14)	Config Key Refresh Phase Get	M	
			Config Key Refresh Phase Set	M	
			Config Key Refresh Phase Status		M

Element	SIG Model ID	States	Messages	Rx	Tx
		Heartbeat Publication (see Section 4.2.17)	Config Heartbeat Publication Get	M	
			Config Heartbeat Publication Set	M	
			Config Heartbeat Publication Status		M
		Heartbeat Subscription (see Section 4.2.18)	Config Heartbeat Subscription Get	M	
			Config Heartbeat Subscription Set	M	
			Config Heartbeat Subscription Status		M
		Network Transmit (see Section 4.2.19)	Config Network Transmit Get	M	
			Config Network Transmit Set	M	
			Config Network Transmit Status		M

Table 4.110: Configuration Server elements, states, and messages

4.4.1.2 Behavior

This section describes behaviors for states and messages for this server model.

Configuration Server messages shall be secured using a DevKey.

4.4.1.2.1 Secure Network Beacon state

When an element receives a Config Beacon Get message, it shall respond with a Config Beacon Status message with the Beacon field set to the current Secure Network Beacon state.

When an element receives a Config Beacon Set message, it shall set the Secure Network Beacon state to the value of the Beacon field of the message and respond with a Config Beacon Status message with the Beacon field set to the current Secure Network Beacon state.

4.4.1.2.2 Composition Data state

When an element receives a Config Composition Data Get message with the Page field of the message containing a value of a Composition Data Page that the node contains, it shall respond with a Config Composition Data Status message with the Page field set to the page number of the Composition Data and the Data field set to the value of the Composition Data Page.

When an element receives a Config Composition Data Get message with the Page field of the message containing a reserved page number or a page number the node does not support, it shall respond with a Config Composition Data Status message with the Page field set to the largest page number of the Composition Data that the node supports and the Data field set to the value of the Composition Data Page for that page number.

Note: It is possible to read all supported Composition Data Pages by reading 0xFF first, and then reading one less than the returned page number until the page number is 0x00.

Note: In this specification, as only page 0 is defined, reading page 0xFF will always return page 0x00, but will in the future return larger page numbers first, before allowing the client to read page 0x00 later.

4.4.1.2.3 *Default TTL state*

When an element receives a Config Default TTL Get message, it shall respond with a Config Default TTL Status message with the TTL field set to the current Default TTL state.

When an element receives a Config Default TTL Set message, it shall set the Default TTL state to the value of the TTL field of the message and respond with a Config Default TTL Status message with the TTL field set to the current Default TTL state.

4.4.1.2.4 *GATT Proxy state*

When an element receives a Config GATT Proxy Get message, it shall respond with a Config GATT Proxy Status message with the GATTProxy field set to the current GATT Proxy state.

When an element receives a Config GATT Proxy Set message and the node supports the Mesh GATT Proxy Service, it shall set the GATT Proxy state to the value of the GATTProxy field of the message and respond with a Config GATT Proxy Status message with the GATTProxy field set to the current GATT Proxy state.

When an element receives a Config GATT Proxy Set message and the node does not support the Mesh GATT Proxy Service, it shall respond with a Config GATT Proxy Status message with the GATTProxy field set to the current GATT Proxy state.

4.4.1.2.5 *Friend state*

When an element receives a Config Friend Get message, it shall respond with a Config Friend Status message with the Friend field set to the current Friend state.

When an element receives a Config Friend Set message and the node supports the Friend feature, it shall set the Friend state to the value of the Friend field of the message and respond with a Config Friend Status message with the Friend field set to the current Friend state.

When an element receives a Config Friend Set message and the node does not support the Friend feature, it shall respond with a Config Friend Status message with the Friend field set to the current Friend state.

4.4.1.2.6 *Relay state*

When an element receives a Config Relay Get message, it shall respond with a Config Relay Status message with the Relay field set to the current Relay state, and with the RelayRetransmitCount field set to the current Relay Retransmit Count state, and with the RelayRetransmitIntervalSteps field set to the current Relay Retransmit Interval Steps state.

When an element receives a Config Relay Set message and the node supports the Relay feature, it shall set the Relay state to the value of the Relay field of the message, and set the Relay Retransmit Count state to the value of the RelayRetransmitCount field of the message, and set the Relay Retransmit Interval Steps state to the value of the RelayRetransmitIntervalSteps field of the message and respond

with a Config Relay Status message with the Relay field set to the current Relay state, and with the RelayRetransmitCount field set to the current Relay Retransmit Count state, and with the RelayRetransmitIntervalSteps field set to the current Relay Retransmit Interval Steps state.

When an element receives a Config Relay Set message and the node does not support the Relay feature, it shall respond with a Config Relay Status message with the Relay field set to the current Relay state, and setting the RelayRetransmitCount and RelayRetransmitIntervalSteps fields to 0x00.

4.4.1.2.7 Model Publication state

When an element receives a Config Model Publication Get message that is processed successfully (i.e., it does not result in any error conditions listed in [Table 4.111](#)), it shall respond with a Config Model Publication Status message with the current values of the identified Model Publication state, setting the ElementAddress and ModelIdentifier fields as defined by the incoming message and setting the Status field to Success. When the PublishAddress is set to the unassigned address, the values of the AppKeyIndex, CredentialFlag, PublishTTL, PublishPeriod, PublishRetransmitCount, and PublishRetransmitIntervalSteps fields shall be set to 0x00.

Error Condition	Status Code Name (see Table 4.108)
The model defined by ElementAddress and ModelIdentifier does not support the publish mechanism	Invalid Publish Parameters
The unicast address provided in ElementAddress is not known to the node	Invalid Address
The model identified by SIG Model ID or Vendor Model ID is not found in a given element	Invalid Model
The AppKey identified by AppKeyIndex is not known to the node	Invalid AppKey Index
The CredentialFlag cannot be set to 1 since the node does not support Low Power feature	Feature Not Supported

Table 4.111: Error conditions for Model Publication state

When an element receives a Config Model Publication Get message, a Config Model Publication Set message, or a Config Model Publication Virtual Address Set message that is not successfully processed (i.e., it results in an error condition listed in [Table 4.111](#)), it shall respond with the Config Model Publication Status message, setting its fields to the values of the corresponding fields (i.e. the identically named fields) of the incoming message, setting the Status field to a status code (defined in [Table 4.111](#)), and setting all other fields to 0x00.

When an element receives a Config Model Publication Set message or a Config Model Publication Virtual Address Set message that is successfully processed (i.e., it does not result in any error conditions listed in [Table 4.111](#)), it shall update the identified Model Publication state to the corresponding field values (defined in [Table 4.112](#)) and respond with a Config Model Publication Status message with the current values of the identified Model Publication state, setting the ElementAddress and ModelIdentifier fields as defined by the incoming message and setting the Status field to Success. When the Publish Address field of a Config Model Publication Set message is set to the unassigned address, the publication of the model shall be disabled and the AppKeyIndex, CredentialFlag, PublishTTL, PublishPeriod, PublishRetransmitCount, and PublishRetransmitIntervalSteps shall be ignored.



State	Message Field
Publication Publish AppKey Index	AppKeyIndex
Publish Friendship Credentials Flag	CredentialFlag
Publication Publish TTL	PublishTTL
Publication Publish Period	PublishPeriod
Publish Retransmit Count	PublishRetransmitCount
Publish Retransmit Interval Steps	PublishRetransmitIntervalSteps
Publication Publish Address	PublishAddress

Table 4.112: Model Publication state to message field mappings

When an element receives a Config Model Publication Set message or a Config Model Publication Virtual Address Set message that is not successfully processed (i.e., it results in an error conditions listed in [Table 4.108](#)), it shall respond with a Config Model Publication Status message setting the ElementAddress and ModelIdentifier fields to the corresponding fields of the incoming message, setting the Status field to a status code (defined in [Table 4.108](#)), and setting all other fields to 0x00.

4.4.1.2.8 Subscription List state

When an element receives a Config Model Subscription Add message or a Config Model Subscription Virtual Address Add message that is successfully processed (i.e., it does not result in any error conditions listed in [Table 4.113](#)) and requesting to add an Address that is not existing in the identified Subscription List, it shall add value of the Address field to the identified Subscription List and respond with a Config Model Subscription Status message setting the Address, ElementAddress, and ModelIdentifier fields as defined by the incoming message and setting the Status field to Success.

Error Condition	Status Code Name (see Table 4.108)
The model defined by ElementAddress and ModelIdentifier does not support subscription mechanism	Not a Subscribe Model
The device cannot store new address due to insufficient resources on device	Insufficient Resources
The unicast address provided in ElementAddress is not known to the node	Invalid Address
The model identified by SIG Model ID or Vendor Model ID is not found in a given element	Invalid Model

Table 4.113: Error conditions for Subscription List state

When an Element receives a Config Model Subscription Add message or a Config Model Subscription Virtual Address Add message that is successfully processed (i.e., it does not result in any error conditions listed in [Table 4.113](#)) and requesting to add an Address that is existing in the identified Subscription List, it shall respond with a Config Model Subscription Status message setting the Address, ElementAddress, and ModelIdentifier fields as defined by the incoming message and setting the Status field to Success.

When an element receives a Config Model Subscription Add message or a Config Model Subscription Virtual Address Add message that is not successfully processed (i.e., it results in an error condition listed



in [Table 4.113](#)), it shall respond with the Config Model Subscription Status message, setting its fields to the values of the corresponding fields (i.e., the identically named fields) of the incoming message and setting the Status field to a status code (defined in [Table 4.113](#)), and setting all other fields to 0.

When an element receives a Config Model Subscription Delete message or a Config Model Subscription Virtual Address Delete message that is successfully processed (i.e., it does not result in any error conditions listed in [Table 4.113](#)) and requesting to delete an Address that is existing in the identified Subscription List, it shall delete the value of the Address field from the identified Subscription List and respond with a Config Model Subscription Status message setting the Address, ElementAddress, and ModelIdentifier fields as defined by the incoming message and setting the Status field to Success.

When an Element receives a Config Model Subscription Delete message or a Config Model Subscription Virtual Address Delete message that is successfully processed (i.e., it does not result in any error conditions listed in [Table 4.113](#)) and requesting to delete an Address that is not existing in the identified Subscription List, it shall respond with a Config Model Subscription Status message setting the Address, ElementAddress, and ModelIdentifier fields as defined by the incoming message and setting the Status field to Success.

When an element receives a Config Model Subscription Delete message or a Config Model Subscription Virtual Address Delete message that is not successfully processed (i.e., it results in an error condition listed in [Table 4.113](#)), it shall respond with the Config Model Subscription Status message, setting its fields to the values of the corresponding fields of the incoming message and setting the Status field to a status code (defined in [Table 4.113](#)), and setting all other fields to 0.

When an element receives a Config Model Subscription Overwrite message or a Config Model Subscription Virtual Address Overwrite message that is successfully processed (i.e., it does not result in any error conditions listed in [Table 4.113](#)), it shall clear the identified Subscription List, add the value of the Address field to the identified Subscription List, and respond with a Config Model Subscription Status message setting the Address, ElementAddress, and ModelIdentifier fields as defined by the incoming message and setting the Status field to Success.

When an element receives a Config Model Subscription Overwrite message or a Config Model Subscription Virtual Address Overwrite message that is not successfully processed (i.e., it results in an error condition listed in [Table 4.113](#)), it shall respond with the Config Model Subscription Status message, setting its fields to the values of the corresponding fields of the incoming message and setting the Status field to a status code (defined in [Table 4.113](#)).

When an element receives a Config Model Subscription Delete All message that is successfully processed (i.e., it does not result in any error conditions listed in [Table 4.113](#)), it shall clear the identified Subscription List and respond with a Config Model Subscription Status message, setting the ElementAddress and ModelIdentifier fields as defined by the incoming message, setting the Address field to unassigned address value, and setting the Status field to Success.

When an element receives a Config Model Subscription Delete All message that is not successfully processed (i.e., it results in an error condition listed in [Table 4.113](#)), it shall respond with the Config Model Subscription Status message, setting its fields to the values of the corresponding fields of the incoming message, setting the Address field to unassigned address value, and setting the Status field to a status code (defined in [Table 4.113](#)), and setting all other fields to 0.

When an element receives a Config SIG Model Subscription Get message that is processed successfully (i.e., it does not result in any error conditions listed in [Table 4.113](#)), it shall respond with a Config SIG Model Subscription List message with the current values of the identified Subscription List state, setting the ElementAddress and ModelIdentifier fields as defined by the incoming message and setting the Status field to Success.

When an element receives a Config Vendor Model Subscription Get message that is processed successfully (i.e., it does not result in any error conditions listed in [Table 4.113](#)), it shall respond with a Config Vendor Model Subscription List message with the current values of the identified Subscription List state, setting the ElementAddress and ModelIdentifier fields as defined by the incoming message and setting the Status field to Success.

When an element receives a Config SIG Model Subscription Get message that is not successfully processed (i.e., it results in an error condition listed in [Table 4.113](#)), it shall respond with the Config SIG Model Subscription List message, setting its fields to the values of the corresponding fields of the incoming message, setting the Status field to a status code (defined in [Table 4.113](#)), and setting the Addresses field to a zero-length (empty) list.

When an element receives a Config Vendor Model Subscription Get message that is not successfully processed (i.e., it results in an error condition listed in [Table 4.113](#)), it shall respond with the Config Vendor Model Subscription List message, setting its fields to the values of the corresponding fields of the incoming message, setting the Status field to a status code (defined in [Table 4.113](#)), and setting the Addresses field to a zero-length (empty) list.

4.4.1.2.9 NetKey List state

When an element receives a Config NetKey Add message that is successfully processed (i.e., it does not result in any error conditions listed in [Table 4.114](#)), it shall add a new NetKey identified by the NetKeyIndex field to the NetKey List and respond with a Config NetKey Status message, setting the NetKeyIndex field as defined by the incoming message, and setting the Status field to Success.

Note: When an element receives a Config NetKey Add message that identifies a NetKey that has already been added to the NetKey List, it responds with Success, because the result of adding the key again, with the same NetKey value, using the same NetKeyIndex will be the same as the result of adding the key the first time.

Error Condition	Status Code Name (see Table 4.108)
The NetKey identified by NetKeyIndex is already stored in the node and the new NetKey value is different	Key Index Already Stored
The key identified by NetKeyIndex is not valid for this device for Config NetKey Update message	Invalid NetKey Index
The node cannot store the new key due to insufficient resources	Insufficient Resources
The requested delete operation cannot be performed due to general constraints	Cannot Remove
The requested update operation cannot be performed due to general constraints	Cannot Update

Table 4.114: Error conditions for NetKey List state



When an element receives a Config NetKey Add message that is not successfully processed (i.e., it results in an error condition listed in [Table 4.114](#)), it shall respond with a Config NetKey Status message, setting the NetKeyIndex field as defined by the incoming message, and setting the Status field to a status code (defined in [Table 4.114](#)).

When an element receives a Config NetKey Update message that is successfully processed (i.e., it does not result in any error conditions listed in [Table 4.114](#)), it shall update the value of the NetKey identified by NetKeyIndex field and respond with a Config NetKey Status message, setting the NetKeyIndex field as defined by the incoming message, and setting the Status field to Success.

When an element receives a Config NetKey Update message that is not successfully processed (i.e., it results in an error condition listed in [Table 4.114](#)), it shall respond with a Config NetKey Status message, setting the NetKeyIndex field as defined by the incoming message, and setting the Status field to a status code (defined in [Table 4.114](#)).

When an element receives a Config NetKey Delete message that is successfully processed (i.e., it does not result in any error conditions listed in [Table 4.114](#)), it shall delete NetKey identified by NetKeyIndex field from the NetKey List, delete all AppKeys bound to the deleted NetKey, and respond with a Config NetKey Status message, setting the NetKeyIndex field as defined by the incoming message, and setting the Status field to Success. When an AppKey used in model Publication is deleted as a result of the processing of the Config NetKey Delete message, the publication for the appropriate models shall be disabled. When NetKey used in Heartbeat Publication is deleted as a result of the processing of the Config NetKey Delete message, the Publication for the appropriate NetKey shall be disabled. When the Mesh Proxy Service is exposed and the NetKey of the subnet utilized in advertising using Node Identity is deleted, the Node Identity state of the subnet of the deleted NetKey shall be set to 0x00.

Note: When an element receives a Config NetKey Delete message that identifies a NetKey that is not in the NetKey List, it responds with Success, because the result of deleting the key that does not exist in the NetKey List will be the same as if the key was deleted from the NetKey List.

When an element receives a Config NetKey Delete message that is not successfully processed (i.e., it results in an error condition listed in [Table 4.114](#)), it shall respond with a Config NetKey Status message, setting the NetKeyIndex field as defined by the incoming message, and setting the Status field to a status code (defined in [Table 4.114](#)).

When an element receives a Config NetKey Get message, it shall respond with a Config NetKey List message, setting the NetKeyIndexes field to a list of all indexes of NetKeys known to the node.

A NetKey shall not be deleted from the NetKey List using a message secured with this NetKey.

4.4.1.2.10 AppKey List state

When an element receives a Config AppKey Add message that is successfully processed (i.e., it does not result in any error conditions listed in [Table 4.115](#)), it shall add a new AppKey identified by AppKeyIndex field to the AppKey List, bind the new AppKey to the NetKey referenced by the NetKeyIndex, and respond with a Config AppKey Status message, setting the NetKeyIndexAndAppKeyIndex field as defined by the incoming message, and setting the Status field to Success.



Note: When an element receives a Config AppKey Add message that identifies an AppKey that has already been added to the AppKey List, it responds with Success, because the result of adding the key again, with the same AppKey value, using the same AppKeyIndex will be the same as the result of adding the key the first time.

Error Condition	Status Code Name (see Table 4.108)
The AppKey identified by AppKeyIndex is already stored in the node and the new AppKey is different	Key Index Already Stored
The node cannot store the new key due to insufficient resources	Insufficient Resources
The key identified by AppKeyIndex is not valid for this device	Invalid AppKey Index
The key identified by NetKeyIndex is not valid for this device	Invalid NetKey Index
The requested update operation cannot be performed due to general constraints	Cannot Update
The NetKeyIndexAndAppKeyIndex combination is not valid for a Config AppKey Update message	Invalid Binding

Table 4.115: Error Conditions for AppKey List state

When an element receives a Config AppKey Add message that is not successfully processed (i.e., it results in an error condition listed in [Table 4.115](#)), it shall respond with a Config AppKey Status message, setting the NetKeyIndexAndAppKeyIndex field as defined by the incoming message, and setting the Status field to a status code (defined in [Table 4.115](#)).

When an element receives a Config AppKey Update message that is successfully processed (i.e., it does not result in any error conditions listed in [Table 4.115](#)), it shall update the value of the AppKey identified by the AppKeyIndex field to the AppKey List and respond with a Config AppKey Status message, setting the NetKeyIndexAndAppKeyIndex field as defined by the incoming message, and setting the Status field to Success.

When an element receives a Config AppKey Update message that is not successfully processed (i.e., it results in an error condition listed in [Table 4.115](#)), it shall respond with a Config AppKey Status message, setting the NetKeyIndexAndAppKeyIndex field as defined by the incoming message, and setting the Status field to a status code (defined in [Table 4.115](#)).

When an element receives a Config AppKey Delete message that is successfully processed (i.e., it does not result in any error conditions listed in [Table 4.115](#)), it shall delete the AppKey identified by the AppKeyIndex field from the AppKey List and respond with a Config AppKey Status message, setting the NetKeyIndexAndAppKeyIndex field as defined by the incoming message, and setting the Status field to Success. When an AppKey used in Model Publication is deleted as a result of the processing of the Config AppKey Delete message, the publication for the appropriate models shall be disabled.

Note: When an element receives a Config AppKey Delete message that identifies an AppKey that is not in the AppKey List, it responds with Success, because the result of deleting the key that does not exist in the AppKey List will be the same as if the key was deleted from the AppKey List.

When an element receives a Config AppKey Delete message that is not successfully processed (i.e., it results in an error condition listed in [Table 4.115](#)), it shall respond with a Config AppKey Status message,



setting the NetKeyIndexAndAppKeyIndex field as defined by the incoming message, and setting the Status field to a status code (defined in [Table 4.115](#)).

When an element receives a Config AppKey Get message that is successfully processed (i.e., it does not result in any error conditions listed in [Table 4.115](#)), it shall respond with a Config AppKey List message, setting the AppKeyIndexes field to a list of all indexes of AppKeys bound to the NetKey identified by the NetKeyIndex field, setting the NetKeyIndex field as defined by the incoming message, and setting the Status field to Success.

When an element receives a Config AppKey Get message that is not successfully processed (i.e., it results in an error condition listed in [Table 4.115](#)), it shall respond with a Config AppKey List message, setting the NetKeyIndex field as defined by the incoming message, setting the Status field to a status code (defined in [Table 4.115](#)), and setting the AppKeyIndexes field to a zero-length (empty) list.

4.4.1.2.11 Model to AppKey List state

When an element receives a Config Model App Bind message that is successfully processed (i.e., it does not result in any error conditions listed in [Table 4.116](#)), it shall bind the AppKey referenced by the AppKeyIndex to the identified Model and respond with a Config Model App Status message, setting the ElementAddress, AppKeyIndex, and ModelIdentifier fields as defined by the incoming message, and setting the Status field to Success.

When an element receives a Config Model App Bind message that is not successfully processed (i.e., it results in an error condition listed in [Table 4.116](#)), it shall respond with the Config Model App Status message, setting its fields to the values of the corresponding fields (i.e., the identically named fields) of the incoming message, and setting the Status field to a status code (defined in [Table 4.116](#)).

Error Condition	Status Code Name (see Table 4.108)
The model identified by SIG Model ID or Vendor Model ID is not found for a given element	Invalid Model
The unicast address provided in ElementAddress is not used by the node	Invalid Address
The key identified by AppKeyIndex is not stored in the node	Invalid AppKey Index
The node cannot store new binding due to insufficient resources	Insufficient Resources
The requested bind operation cannot be performed due to general constraints	Cannot Bind

Table 4.116: Error Conditions for Model to AppKey List state

When an element receives a Config Model App Unbind message that is successfully processed (i.e., it does not result in any error conditions listed in [Table 4.116](#)), it shall unbind the AppKey referenced by the AppKeyIndex from the identified model and respond with a Config Model App Status message, setting the ElementAddress, AppKeyIndex, and ModelIdentifier fields as defined by the incoming message, and setting the Status field to Success. When the specified AppKeyIndex is used by the identified model as a Publish AppKeyIndex the Model Publication, the publication for the model shall be disabled.

When an element receives a Config Model App Unbind message that is not successfully processed (i.e., it results in an error condition listed in [Table 4.116](#)), it shall respond with the Config Model App Status



message, setting its fields to the values of the corresponding fields of the incoming message, and setting the Status field to a status code (defined in [Table 4.116](#)).

When an element receives a Config SIG Model App Get message that is processed successfully (i.e., it does not result in any error conditions listed in [Table 4.116](#)), it shall respond with a Config SIG Model App List message with the current values of the identified Model to AppKey List, setting the ElementAddress and ModelIdentifier fields as defined by the incoming message, and setting the Status field to Success.

When an element receives a Config SIG Model App Get message that is not successfully processed (i.e., it results in an error condition listed in [Table 4.116](#)), it shall respond with the Config SIG Model App List message, setting its fields to the values of the ElementAddress and ModelIdentifier of the incoming message, setting the Status field to a status code (defined in [Table 4.116](#)), and setting the AppKeyIndexes field to a zero-length (empty) list.

When an element receives a Config Vendor Model App Get message that is processed successfully (i.e., it does not result in any error conditions listed in [Table 4.116](#)), it shall respond with a Config Vendor Model App List message with the current values of the identified Model to AppKey List, setting the ElementAddress and ModelIdentifier fields as defined by the incoming message, and setting the Status field to Success.

When an element receives a Config Vendor Model App Get message that is not successfully processed (i.e., it results in an error condition listed in [Table 4.116](#)), it shall respond with the Config Vendor Model App List message, setting its fields to the values of the ElementAddress and ModelIdentifier of the incoming message, setting the Status field to a status code (defined in [Table 4.116](#)), and setting the AppKeyIndexes field to a zero-length (empty) list.

4.4.1.2.12 Node Identity state

When an element receives a Config Node Identity Get message that is successfully processed (i.e., it does not result in any error conditions listed in [Table 4.117](#)), it shall respond with a Config Node Identity Status message with the Identity field set to the current Node Identity state identified by the NetKeyIndex field, setting the NetKeyIndex field as defined by the incoming message, and setting the Status field to Success.

Error Condition	Status Code Name (see Table 4.108)
The key identified by the NetKeyIndex is not valid for this device	Invalid NetKey Index
The node cannot start advertising with Node Identity since the maximum number of parallel advertising is reached	Temporarily Unable to Change State

Table 4.117: Error Conditions for Node Identity state

When an element receives a Config Node Identity Get message that is not successfully processed (i.e., it results in any error conditions listed in [Table 4.117](#)), it shall respond with a Config Node Identity Status message, setting the NetKeyIndex field as defined by the incoming message, setting the Identity field to 0x00, and setting the Status field to a status code (defined in [Table 4.117](#)).

When an element receives a Config Node Identity Set message that is successfully processed (i.e., it does not result in any error conditions listed in [Table 4.117](#)), it shall set the Node Identity state identified

by the NetKeyIndex field to the value of the Identity field of the message and respond with a Config Node Identity Status message with the Identity field set to the current Node Identity state of the NetKey, setting the NetKeyIndex field as defined by the incoming message, and setting the Status field to Success.

When an element receives a Config Node Identity Set message that is not successfully processed (i.e., it results in any error conditions listed in [Table 4.117](#)), it shall respond with a Config Node Identity Status message, setting the NetKeyIndex and Identity fields as defined by the incoming message, and setting the Status field to a status code defined in ([Table 4.117](#)).

4.4.1.2.13 Reset

When an element receives a Config Node Reset message, it shall perform the Node Removal procedure (see Section [3.10.7](#)) and respond with a Config Node Reset Status message.

4.4.1.2.14 Key Refresh Phase state

When an element receives a Config Key Refresh Phase Get message that is successfully processed (i.e., it does not result in any error conditions listed in [Table 4.118](#)), it shall respond with a Config Key Refresh Phase Status message with the Phase field set to the current Key Refresh Phase state, setting the NetKeyIndex field as defined by the incoming message, and setting the Status field to Success.

Error Condition	Status Code Name (see Table 4.108)
The key identified by the NetKeyIndex is not valid for this device	Invalid NetKey Index

Table 4.118: Error Conditions for Key Refresh Phase state

When an element receives a Config Key Refresh Phase Get message that is not successfully processed (i.e., it results in any of the error conditions listed in [Table 4.118](#)), it shall respond with a Config Key Refresh Phase Status message with the Phase field set to 0x00, setting the NetKeyIndex field as defined by the incoming message, and setting the Status field to a status code (defined in [Table 4.118](#)).

When an element receives a Config Key Refresh Phase Set message that is successfully processed (i.e., it does not result in any error conditions listed in [Table 4.118](#)), it shall set the Key Refresh Phase state according to [Table 4.18](#) and respond with a Config Key Refresh Phase Status message with the Phase field set to the current Key Refresh Phase state, setting the NetKeyIndex field as defined by the incoming message, and setting the Status field to Success.

When an element receives a Config Key Refresh Phase Set message that is not successfully processed (i.e., it results in any of the error conditions listed in [Table 4.118](#)), it shall respond with a Config Key Refresh Phase Status message with the Phase field set to 0x00, setting the NetKeyIndex field as defined by the incoming message, and setting the Status field to a status code (defined in [Table 4.118](#)).

4.4.1.2.15 Heartbeat Publication state

When an element receives a Config Heartbeat Publication Get message, it shall respond with a Config Heartbeat Publication Status message with the current values of the identified Heartbeat Publication state, setting the Status field to Success, setting the Destination field to the value of the Heartbeat Publication Destination state, the CountLog field to the Heartbeat Publication Count Log representation of the Heartbeat Publication Count state, the PeriodLog field to the value of the Heartbeat Publication Period

Log state, the TTL field to the value of the Heartbeat Publication TTL state, the Features field to the value of the Heartbeat Publication Features state, and the NetKey Index to the value of the Heartbeat Publication NetKey Index state. When the Destination is set to the unassigned address, the values of the CountLog, PeriodLog, and TTL fields shall be set to 0x00.

Error Condition	Status Code Name (see Table 4.108)
The key identified by the NetKeyIndex is not valid for this device	Invalid NetKey Index

Table 4.119: Error Conditions for Heartbeat Publication state

When an element receives a Config Heartbeat Publication Set message that is not successfully processed (i.e., it results in any of the error conditions listed in [Table 4.119](#)), it shall respond with a Config Heartbeat Publication Status message, setting the Destination, CountLog, PeriodLog, and TTL fields to the values of corresponding fields of the incoming message and setting the Status field to a status code (defined in [Table 4.119](#)).

When an element receives a Config Heartbeat Publication Set message that is successfully processed (i.e., it does not result in any error conditions listed in [Table 4.119](#)), it shall update the identified Heartbeat Publication state to the corresponding field values (defined in [Table 4.120](#)) and the Heartbeat Publication Count state to the corresponding value (defined in the [Table 4.121](#)) and respond with a Config Heartbeat Publication Status message, setting the Status field to Success and setting the Destination, CountLog, PeriodLog, TTL, Features, and NetKeyIndex fields with the current values of the corresponding fields of the Heartbeat Publication state.

State	Message Field
Heartbeat Publication Destination	Destination
Heartbeat Publication Period Log	PeriodLog
Heartbeat Publication TTL	TTL
Heartbeat Publication Features	Features
Heartbeat Publication NetKey Index	NetKeyIndex

Table 4.120: Heartbeat Publication State to Message Field Mappings

CountLog Field Value	Heartbeat Publication Count State
0x00	0x0000
0x01-0x11	2(CountLog-1)
0x12-0xFE	Prohibited
0xFF	0xFFFF

Table 4.121: CountLog Field Value to Heartbeat Publication Count State Mappings

4.4.1.2.16 Heartbeat Subscription state

When an element receives a Config Heartbeat Subscription Get message, it shall respond with a Config Heartbeat Subscription Status message, setting the Status field to Success, setting the Source,



Destination, PeriodLog, CountLog, MinHops and MaxHops fields with the current values of the corresponding fields (defined in [Table 4.122](#)) of the identified Heartbeat Subscription state. When the Heartbeat Subscription Source state or the Heartbeat Subscription Destination state is set to the unassigned address, the value of the Source and Destination fields of the Config Heartbeat Subscription Status message shall be set to the unassigned address and the values of the CountLog, PeriodLog, MinHops, and MaxHops fields shall be set to 0x00.

When an element receives a Config Heartbeat Subscription Set message, it shall update the identified Heartbeat Subscription state to the corresponding field values (defined in [Table 4.122](#)) and respond with a Config Heartbeat Subscription Status message, setting the Status field to Success and setting the Source, Destination, PeriodLog, MinHops, and MaxHops fields with the current values of the corresponding fields of the Heartbeat Subscription state, and setting the CountLog field to the Heartbeat Subscription Count Log representation of the Heartbeat Subscription Count Log state. If the Source or the Destination field is set to the unassigned address, or the PeriodLog field is set to 0x00, then the processing of received Heartbeat messages shall be disabled, the Heartbeat Subscription Source state shall be set to the unassigned address, the Heartbeat Subscription Destination state shall be set to the unassigned address, the Heartbeat Subscription MinHops state shall be unchanged, the Heartbeat Subscription MaxHops state shall be unchanged, and the Heartbeat Subscription Count state shall be unchanged. If the Source field is set to a unicast address, and the Destination field is set to a unicast address or group address, and the PeriodLog field is set to a non-zero value, then the processing of received Heartbeat messages shall be enabled, the Heartbeat Subscription MinHops state shall be set to 0x7F, the Heartbeat Subscription MaxHops state shall be set to 0x00, and the Heartbeat Subscription Count state shall be set to 0x0000.

State	Message Field
Heartbeat Subscription Source	Source
Heartbeat Subscription Destination	Destination
Heartbeat Subscription Period Log	PeriodLog
Heartbeat Subscription Min Hops	MinHops
Heartbeat Subscription Max Hops	MaxHops

Table 4.122: Heartbeat Subscription state to message field mappings

Note: Using heartbeat with LPN nodes as destinations is not recommended as it may cause the Friend Queue to overflow. However, if the subscribing element is within a Low Power Node, it should update the Friend Subscription List (see [Section 3.6.6.4.3](#)).

[4.4.1.2.17 PollTimeout List state](#)

When an element receives a Config Low Power Node PollTimeout Get message, it shall respond with a Config Low Power Node PollTimeout Status message with the PollTimeout field set to the current PollTimeout List state element identified by the value of the LPNAddress field.

[4.4.1.2.18 Network Transmit state](#)

When an element receives a Config Network Transmit Get message, it shall respond with a Config Network Transmit Status message that has the NetworkTransmitCount field set to the current Network

Transmit Count state and the NetworkTransmitIntervalSteps field set to the current Network Transmit Interval Steps state.

When an element receives a Config Network Transmit Set message, it shall set the Network Transmit Count state to the value of the NetworkTransmitCount field and shall set the Network Transmit Interval Steps state to the value of the NetworkTransmitIntervalSteps fields of the message and shall respond with a Config Network Transmit Status message that has the NetworkTransmitCount field set to the current Network Transmit Count state and the NetworkTransmitIntervalSteps field set to the current Network Transmit Interval Steps state.

4.4.1.3 Error handling behavior

When a node receives a message that requires it to store some information in the node's persistent memory and the storage is not successful, the node shall use the Storage Failure as a value of the Status Code. This might be either a permanent or a temporary situation.

When an error occurs that does not correspond to an error condition defined for a given state, the node shall use the Unspecified Error as a value of the Status Code (see [Table 4.108](#)).

4.4.2 Configuration Client model

4.4.2.1 Description

The Configuration Client is a root model (i.e., it does not extend any other models).

The model is used to represent an element that can control and monitor the configuration of a node.

The model defines the elements and procedures listed in [Table 4.123](#) below.

Element	SIG Model ID	Procedure	Messages	Rx	Tx
Primary	0x0001	Secure Network Beacon	Config Beacon Get		M
			Config Beacon Set		M
			Config Beacon Status	M	
		Composition Data	Config Composition Data Get		M
			Config Composition Data Status	M	
		Default TTL	Config Default TTL Get		M
			Config Default TTL Set		M
			Config Default TTL Status	M	
		GATT Proxy	Config GATT Proxy Get		M
			Config GATT Proxy Set		M
			Config GATT Proxy Status	M	
		Friend	Config Friend Get		M
			Config Friend Set		M



Element	SIG Model ID	Procedure	Messages	Rx	Tx
			Config Friend Status	M	
		Relay	Config Relay Get		M
			Config Relay Set		M
			Config Relay Status	M	
		Model Publication	Config Model Publication Get		M
			Config Model Publication Set		M
			Config Model Publication Virtual Address Set		M
			Config Model Publication Status	M	
		Subscription List	Config Model Subscription Add		M
			Config Model Subscription Virtual Address Add		M
			Config Model Subscription Delete		M
			Config Model Subscription Virtual Address Delete		M
			Config Model Subscription Overwrite		M
			Config Model Subscription Virtual Address Overwrite		M
			Config Model Subscription Delete All		M
			Config Model Subscription Status	M	
			Config SIG Model Subscription Get		M
			Config SIG Model Subscription List	M	
			Config Vendor Model Subscription Get		M
			Config Vendor Model Subscription List	M	
		NetKey List	Config NetKey Add		M
			Config NetKey Update		M
			Config NetKey Delete		M
			Config NetKey Status	M	
			Config NetKey Get		M
			Config NetKey List	M	
		AppKey List	Config AppKey Add		M
			Config AppKey Update		M
			Config AppKey Delete		M
			Config AppKey Status	M	

Element	SIG Model ID	Procedure	Messages	Rx	Tx
			Config AppKey Get		M
			Config AppKey List	M	
		Model to AppKey List	Config Model App Bind		M
			Config Model App Unbind		M
			Config Model App Status	M	
			Config SIG Model App Get		M
			Config SIG Model App List	M	
			Config Vendor Model App Get		M
			Config Vendor Model App List	M	
		Node Identity	Config Node Identity Get		M
			Config Node Identity Set		M
			Config Node Identity Status	M	
		Reset	Config Node Reset		M
			Config Node Reset Status	M	
		Key Refresh Phase	Config Key Refresh Phase Get		M
			Config Key Refresh Phase Set		M
			Config Key Refresh Phase Status	M	
		Heartbeat Publication	Config Heartbeat Publication Get		M
			Config Heartbeat Publication Set		M
			Config Heartbeat Publication Status	M	
		Heartbeat Subscription	Config Heartbeat Subscription Get		M
			Config Heartbeat Subscription Set		M
			Config Heartbeat Subscription Status	M	
		Network Transmit	Config Network Transmit Get		M
			Config Network Transmit Set		M
			Config Network Transmit Status	M	

Table 4.123: Configuration Client elements and procedures

4.4.2.2 Behavior

This section describes behaviors for procedures and messages for this client model.

An element can send any Configuration Client message at any time to query or change a configuration state of a peer element. Configuration Client messages shall be secured using a DevKey.

4.4.2.2.1 *Secure Network Beacon procedure*

To determine the Secure Network Beacon state of a Configuration Server, a Configuration Client shall send a Config Beacon Get message. The response is a Config Beacon Status message that contains the Secure Network Beacon state.

To set the Secure Network Beacon state of a Configuration Server with acknowledgment, a Configuration Client shall send a Config Beacon Set message. The response is a Config Beacon Status message that contains the Secure Network Beacon state.

Upon receiving a Config Beacon Status message, a Configuration Client can determine the Secure Network Beacon state of a Configuration Server.

4.4.2.2.2 *Composition Data procedure*

The Composition Data state of a server is composed of one or more pages. To determine the Composition Data state of a Configuration Server, a Configuration Client shall send a Config Composition Data Get message with the Page field value set to 0xFF. The response is a Config Composition Data Status message that contains the last page of the Composition Data state. If the Page field of the Config Composition Data Status message contains a non-zero value, then the Configuration Client shall send another Composition Data Get message with the Page field value set to one less than the Page field value of the Config Composition Data Status message.

4.4.2.2.3 *Default TTL procedure*

To determine the Default TTL state of a Configuration Server, a Configuration Client shall send a Config Default TTL Get message. The response is a Config Default TTL Status message that contains the Default TTL state.

To set the Default TTL state of a Configuration Server with acknowledgment, a Configuration Client shall send a Config Default TTL Set message. The response is a Config Default TTL Status message that contains the Default TTL state.

Upon receiving a Config Default TTL Status message, a Configuration Client can determine the current Default TTL state of a Configuration Server.

4.4.2.2.4 *GATT Proxy procedure*

To determine the GATT Proxy state of a Configuration Server, a Configuration Client shall send a Config GATT Proxy Get message. The response is a Config GATT Proxy Status message that contains the GATT Proxy state.

To set the GATT Proxy state of a Configuration Server with acknowledgment, a Configuration Client shall send a Config GATT Proxy Set message. The response is a Config GATT Proxy Status message that contains the GATT Proxy state.

Upon receiving a Config GATT Proxy Status message, a Configuration Client can determine the current GATT Proxy state of a Configuration Server.



4.4.2.2.5 *Friend procedure*

To determine the Friend state of a Configuration Server, a Configuration Client shall send a Config Friend Get message. The response is a Config Friend Status message that contains the Friend state.

To set the Friend state of a Configuration Server with acknowledgment, a Configuration Client shall send a Config Friend Set message. The response is a Config Friend Status message that contains the Friend state.

Upon receiving a Config Friend Status message, a Configuration Client can determine the Friend state of a Configuration Server.

4.4.2.2.6 *Relay procedure*

To determine the Relay and Relay Retransmit states of a Configuration Server, a Configuration Client shall send a Config Relay Get message. The response is a Config Relay Status message that contains the Relay and Relay Retransmit states.

To set the Relay and Relay Retransmit states of a Configuration Server with acknowledgment, a Configuration Client shall send a Config Relay Set message. The response is a Config Relay Status message that contains the Relay and Relay Retransmit states.

Upon receiving a Config Relay Status message, a Configuration Client can determine the current Relay and Relay Retransmit states of a Configuration Server.

4.4.2.2.7 *Model Publication procedure*

To determine the Publish Address, Publish AppKey Index, CredentialFlag, Publish Period, Publish Retransmit Count, Publish Retransmit Interval Steps, and Publish TTL states of a particular model within the element, a Configuration Client shall send a Config Model Publication Get message. The response is a Config Model Publication Status message that contains a status and may contain the Publish Address, Publish AppKey Index, CredentialFlag, Publish Period, Publish Retransmit Count, Publish Retransmit Interval Steps, and Publish TTL states.

To set the Publish Address, Publish AppKey Index, CredentialFlag, Publish Period, Publish Retransmit Count, Publish Retransmit Interval Steps, and Publish TTL states of a particular model within the element with acknowledgment, a Configuration Client shall send a Config Model Publication Set message. The response is a Config Model Publication Status message that contains a status and may contain the Publish Address, Publish AppKey Index, CredentialFlag, Publish Period, Publish Retransmit Count, Publish Retransmit Interval Steps, and Publish TTL states.

To unset the Publish Address state of a particular model within the element with acknowledgment, a Configuration Client shall send a Config Model Publication Set message with the PublishAddress field set to Unassigned and with the AppKeyIndex, CredentialFlag, PublishTTL, PublishRetransmitCount, PublishRetransmitIntervalSteps, and PublishPeriod fields set to 0.

To set the Label UUID as the Publish Address, Publish AppKey Index, CredentialFlag, Publish Period, and Publish TTL states of a particular model within the element with acknowledgment, a Configuration Client shall send a Config Model Publication Virtual Address Set message. The response is a Config Model Publication Status message that contains a status and may contain the Publish Address, Publish AppKey Index, CredentialFlag, Publish Period, Publish Retransmit Count, Publish Retransmit Interval Steps, and Publish TTL states.



Upon receiving a Config Model Publication Status message, a Configuration Client can determine the status that can be either a Success or an error (see [Table 4.111](#)). If it's Success, the Configuration Client can also determine the current Publish Address, Publish AppKey Index, CredentialFlag, Publish Period, Publish Retransmit Count, Publish Retransmit Interval Steps, and Publish TTL states of a particular model within the element. If it's an error, the Status field shall contain the error condition; and the values of the Publish Address, Publish AppKey Index, CredentialFlag, PublishPeriod, PublishRetransmitCount, PublishRetransmitIntervalSteps, and PublishTTL fields shall be discarded.

4.4.2.2.8 *Subscription List procedure*

To add the address to the Subscription List state of a particular model within the element with acknowledgment, a Configuration Client shall send a Config Model Subscription Add message. The response is a Config Model Subscription Status message that contains a status and may contain the added address value.

To add the Label UUID to the Subscription List state of a particular model within the element with acknowledgment, a Configuration Client shall send a Config Model Subscription Virtual Address Add message. The response is a Config Model Subscription Status message that contains a status and may contain the added address value.

To delete the address from the Subscription List state of a particular model within the element with acknowledgment, a Configuration Client shall send a Config Model Subscription Delete message. The response is a Config Model Subscription Status message that contains a status and may contain the deleted address value.

To delete the Label UUID from the Subscription List state of a particular model within the element with acknowledgment, a Configuration Client shall send a Config Model Subscription Virtual Address Delete message. The response is a Config Model Subscription Status message that contains a status and may contain the deleted address value.

To clear the Subscription List and add the address to the Subscription List state of a particular model within the element with acknowledgment, a Configuration Client shall send a Config Model Subscription Overwrite message. The response is a Config Model Subscription Status message that contains a status and may contain the added address value.

To clear the Subscription List and add the Label UUID to the Subscription List state of a particular model within the element with acknowledgment, a Configuration Client shall send a Config Model Subscription Virtual Address Overwrite message. The response is a Config Model Subscription Status message that contains a status and may contain the added address value.

To clear the Subscription List of the Subscription List state of a particular model within the element with acknowledgment, a Configuration Client shall send a Config Model Subscription Delete All message. The response is a Config Model Subscription Status message that contains a status.

Note: After adding a previously not known group address to one of the node's subscription lists, the node is not protected against a replay attack utilizing messages to that new group address. It is therefore strongly recommended that the Configuration Client run, for a brief period of time, a Heartbeat Subscription procedure on the node and a Heartbeat Publication procedure on all nodes that publish to the new group address to initialize the replay protection list of the node with the current value of the sequence numbers for all affected publishers.

Upon receiving a Config Model Subscription Status message, a Configuration Client can determine the status that can be either a Success or an error (see [Table 4.113](#)). If it's Success, the Configuration Client may determine the address that was used to change the Subscription List state of a particular model within the element. If it's an error, the Status field will contain the error condition.

To determine the Subscription List state of a particular SIG Model within the element, a Configuration Client shall send a Config SIG Model Subscription Get message. The response is a Config SIG Model Subscription List message that contains a status and may contain the Subscription List state.

To determine the Subscription List state of a particular Vendor Model within the element, a Configuration Client shall send a Config Vendor Model Subscription Get message. The response is a Config Vendor Model Subscription List message that contains a status and may contain the Subscription List state.

Upon receiving a Config SIG Model Subscription List message or a Config Vendor Model Subscription List message, a Configuration Client can determine the status that can be either a Success or an error (see [Table 4.113](#)). If it's Success, the Configuration Client can also determine the current Subscription List state of a particular model within the element. If it's an error, the Status field will contain the error condition, and the Addresses field will be set to a zero-length (empty) list.

4.4.2.2.9 *NetKey List procedure*

To add the NetKey identified by NetKeyIndex to the NetKey List state with acknowledgment, a Configuration Client shall send a Config NetKey Add message. The response is a Config NetKey Status message that contains a status and the NetKeyIndex value.

To update the NetKey identified by NetKeyIndex to the NetKey List state with acknowledgment, a Configuration Client shall send a Config NetKey Update message. The response is a Config NetKey Status message that contains a status and the NetKeyIndex value.

To delete the NetKey identified by NetKeyIndex to the NetKey List state with acknowledgment, a Configuration Client shall send a Config NetKey Delete message. The response is a Config NetKey Status message that contains a status and the NetKeyIndex value.

Upon receiving a Config NetKey Status message, a Configuration Client can determine the status that can be either a Success or an error (see [Table 4.114](#)) and the NetKeyIndex value. If it's Success, the Status field will be set to Success. If it's an error, the Status field will contain the error condition.

To determine the NetKey List of the Configuration Server, a Configuration Client shall send a Config NetKey Get message. The response is a Config NetKey List message that contains a NetKey List.

Upon receiving a Config NetKey List message, a Configuration Client can determine the current NetKey List of a Configuration Server.

4.4.2.2.10 *AppKey List procedure*

To add the AppKey to the AppKey List and bind it to the NetKey identified by the NetKeyIndex of a Configuration Server with acknowledgment, a Configuration Client shall send a Config AppKey Add message. The response is a Config AppKey Status message that contains a status, the added AppKey index, and the NetKeyIndex value.

To update the value of the AppKey from the AppKey List of the NetKey identified by the NetKeyIndex of a Configuration Server with acknowledgment, a Configuration Client shall send a Config AppKey Update message. The response is a Config AppKey Status message that contains a status, the added AppKey index, and the NetKeyIndex value.

To delete the AppKey from the AppKey List of the NetKey identified by the NetKeyIndex of a Configuration Server with acknowledgment, a Configuration Client shall send a Config AppKey Delete message. The response is a Config AppKey Status message that contains a status, the deleted AppKey index, and the NetKeyIndex value.

Upon receiving a Config AppKey Status message, a Configuration Client can determine the status that can be either a Success or an error (see [Table 4.115](#)). If it's Success, the Configuration Client can determine the AppKey index that was used to change the AppKey List of the NetKey identified by the NetKeyIndex of a Configuration Server. If it's an error, the Status field will contain the error condition.

To determine the AppKey List of the NetKey identified by the NetKeyIndex of a Configuration Server, a Configuration Client shall send a Config AppKey Get message. The response is a Config AppKey List message that contains a status and may contain the AppKey List.

Upon receiving a Config AppKey List message, a Configuration Client can determine the status that can be either a Success or an error (see [Table 4.115](#)). If it's Success, the Configuration Client can also determine the current AppKey List of the NetKey identified by the NetKeyIndex of a Configuration Server. If it's an error, the Status field will contain the error condition, and the AppKeyIndexes field will be set to a zero-length (empty) list.

4.4.2.2.11 *Model to AppKey List procedure*

To bind the AppKey to a model of a particular element of a Configuration Server with acknowledgment, a Configuration Client shall send a Config Model App Bind message. The response is a Config Model App Status message that contains a status and other fields set to the values of the corresponding fields (i.e., the identically named fields) of the incoming message.

To unbind the AppKey from a model of a particular element of a Configuration Server with acknowledgment, a Configuration Client shall send a Config Model App Unbind message. The response is a Config Model App Status message that contains a status and other fields set to the values of the corresponding fields of the incoming message.

Upon receiving a Config Model App Status message, a Configuration Client can determine the status that can be either a Success or an error (see [Table 4.116](#)). If it's Success, the Configuration Client can also determine the values of the ElementAddress, AppKeyIndex, and ModelIdentifier that were used to change the Model to AppKey List state. If it's an error, the Status field will contain the error condition.

To determine the Model to AppKey List of a particular SIG Model within the element, a Configuration Client shall send a Config SIG Model App Get message. The response is a Config SIG Model App List message that contains a status and may contain the Model to AppKey List.

Upon receiving a Config SIG Model App List message, a Configuration Client can determine the status that can be either a Success or an error (see [Table 4.116](#)). If it's Success, the Configuration Client can also determine the current Model to AppKey List of a particular SIG Model within the element. If it's an

error, the Status field will contain the error condition, and the AppKeyIndexes field will be set to a zero-length (empty) list.

To determine the Model to AppKey List of a particular Vendor Model within the element, a Configuration Client shall send a Config Vendor Model App Get message. The response is a Config Vendor Model App List message that contains a status and may contain the Model to AppKey List.

Upon receiving a Config Vendor Model App List message, a Configuration Client can determine the status that can be either a Success or an error (see [Table 4.116](#)). If it's Success, the Configuration Client can also determine the current Model to AppKey List of a particular Vendor model within the element. If it's an error, the Status field will contain the error condition, and the AppKeyIndexes field will be set to a zero-length (empty) list.

4.4.2.2.12 Node Identity procedure

To determine the Node Identity state of the NetKey identified by the NetKeyIndex of a Configuration Server, a Configuration Client shall send a Config Node Identity Get message. The response is a Config Node Identity Status message that contains a status, NetKeyIndex value, and the Node Identity state of the NetKey.

To set the Node Identity state of the NetKey identified by the NetKeyIndex of a Configuration Server with acknowledgment, a Configuration Client shall send a Config Node Identity Set message. The response is a Config Node Identity Status message that contains a status, NetKeyIndex value, and the Node Identity state.

Upon receiving a Config Node Identity Status message, a Configuration Client can determine the status that can be either Success or an error (see [Table 4.117](#)). If it's Success, the Configuration Client can also determine the current Node Identity state of the NetKey identified by the NetKeyIndex of a Configuration Server. If it's an error, the Status field will contain the error condition, and the Identity field will be set to zero.

4.4.2.2.13 Reset procedure

To initiate the Node Removal procedure of a Configuration Server with acknowledgment, a Configuration Client shall send a Config Node Reset message. The response is a Config Node Reset Status message.

Upon receiving a Config Node Reset Status message, a Configuration Client can determine that the Node Removal procedure was initiated on a Configuration Server.

4.4.2.2.14 Key Refresh Phase procedure

To determine the Key Refresh Phase state of a Configuration Server, a Configuration Client shall send a Config Key Refresh Phase Get message. The response is a Config Key Refresh Phase Status message that contains a status, the NetKeyIndex value, and the Key Refresh Phase state.

To set the Key Refresh Phase state of a Configuration Server with acknowledgment, a Configuration Client shall send a Config Key Refresh Phase Set message. The response is a Config Key Refresh Phase Status message that contains a status, the NetKeyIndex value, and the Key Refresh Phase state.

Upon receiving a Config Key Refresh Phase Status message, a Configuration Client can determine the status that can be either a Success or an error (see [Table 4.118](#)). If it's Success, the Configuration Client



can also determine the current Key Refresh Phase state of the NetKey identified by the NetKeyIndex of a Configuration Server. If it's an error, the Status field will contain the error condition.

4.4.2.2.15 *Heartbeat Publication procedure*

A configuration client may use the Heartbeat Publication and Heartbeat Subscription procedures to map a topology of the subnet. Using the Heartbeat Publication procedure sets one node to publish a series of Heartbeat messages (see Section 3.6.5.10), and using the Heartbeat Subscription procedure sets another node to process received Heartbeat messages and report them to the configuration client.

To determine the Heartbeat Publication Destination, Heartbeat Publication Count Log representation of the Heartbeat Publication Count state, Heartbeat Publication Period Log, Heartbeat Publication TTL, Heartbeat Publication Features, and Heartbeat NetKey Index states of a node, a Configuration Client shall send a Config Heartbeat Publication Get message. The response is a Config Heartbeat Publication Status message that contains the Heartbeat Publication Destination, Heartbeat Publication Count Log representation of the Heartbeat Publication Count state, Heartbeat Publication Period Log, Heartbeat Publication TTL, Heartbeat Publication Features and Heartbeat Publication NetKey Index states.

To set the Heartbeat Publication Destination, Heartbeat Publication Count, Heartbeat Publication Period, Heartbeat Publication TTL, Publication Features, and Publication NetKey Index of a node with acknowledgment, a Configuration Client shall send a Config Heartbeat Publication Set message. The response is a Config Heartbeat Publication Status message that contains a Status of the operation and the Heartbeat Publication Destination, Heartbeat Publication Count Log representation of the Heartbeat Publication Count state, Heartbeat Publication Period Log, Heartbeat Publication TTL, Heartbeat Publication Features, and Heartbeat Publication NetKey Index states.

Upon receiving a Config Heartbeat Publication Status message, a Configuration Client can determine the status that can be either a Success or an error (see Table 4.119). If it's Success, the Configuration Client can also determine the current Heartbeat Publication Destination, Heartbeat Publication Count Log representation of the Heartbeat Publication Count state, Heartbeat Publication Period Log, Heartbeat Publication TTL, Heartbeat Publication Features, and Heartbeat Publication NetKey Index states of a node. If it's an error, the Status field will contain the error condition.

4.4.2.2.16 *Heartbeat Subscription procedure*

To determine the Heartbeat Subscription Source, Heartbeat Subscription Destination, Heartbeat Subscription Count Log representation of the Heartbeat Subscription Count state, Heartbeat Subscription Period Log, Heartbeat Subscription Min Hops, and Heartbeat Subscription Max Hops states of a node, a Configuration Client shall send a Config Heartbeat Subscription Get message. The response is a Config Heartbeat Subscription Status message that contains the Heartbeat Subscription Source, Heartbeat Subscription Destination, Heartbeat Subscription Count Log representation of the Heartbeat Subscription Count state, Heartbeat Subscription Period Log, Heartbeat Subscription Min Hops, and Heartbeat Subscription Max Hops states.

To set the Heartbeat Subscription Source, Heartbeat Subscription Destination, Heartbeat Subscription Count, and Heartbeat Subscription Period states of a node with acknowledgment, a Configuration Client shall send a Config Heartbeat Subscription Set message. The response is a Config Heartbeat Subscription Status message that contains a Status of the operation and the Heartbeat Subscription Source, Heartbeat Subscription Destination, Heartbeat Subscription Count Log representation of the



Heartbeat Subscription Count state, Heartbeat Subscription Period Log, Heartbeat Subscription Min Hops, and Heartbeat Subscription Max Hops states.

Upon receiving a Config Heartbeat Subscription Status message, a Configuration Client can determine the current Heartbeat Subscription Source, Heartbeat Subscription Destination, Heartbeat Subscription Count Log representation of the Heartbeat Subscription Count state, Heartbeat Subscription Period Log, Heartbeat Subscription Min Hops, and Heartbeat Subscription Max Hops states of a node.

4.4.2.2.17 *PollTimeout List procedure*

To determine the current PollTimeout List state value of a Configuration Server, a Configuration Client shall send a Config Low Power Node PollTimeout Get message with the LPNAddress field set to the primary unicast address of the Low Power node. The response is a Config Low Power Node PollTimeout Status message that contains the current value of the PollTimeout List state for that LPNAddress.

4.4.2.2.18 *Network Transmit procedure*

To determine the Network Transmit state of a Configuration Server, a Configuration Client shall send a Config Network Transmit Get message. The response is a Config Network Transmit Status message that contains the Network Transmit state.

To set the Network Transmit state of a Configuration Server with acknowledgment, a Configuration Client shall send a Config Network Transmit Set message. The response is a Config Network Transmit Status message that contains the Network Transmit state.

Upon receiving a Config Network Transmit Status message, a Configuration Client can determine the Network Transmit state of a Configuration Server.

4.4.3 Health Server model

4.4.3.1 Description

The Health Server is a root model (i.e., it does not extend any other models).

This model shall support model publication (see Section 4.2.2) and model subscription (see Section 4.2.3).

This model is used to represent a mesh network diagnostics of a device.

The model shall be supported by a primary element and may be supported by any secondary elements. The application-layer security on the model is using application keys.

The model defines the following state instances as shown in Table 4.124 below:



Health Server States		Bound States		
State	Instance	Model	State	Instance
Current Fault	Primary	-	-	-
Registered Fault	Primary	-	-	-
Health Period	Primary	-	-	-
Attention Timer	Primary	-	-	-

Table 4.124: Health Server states and bindings

The structure of elements, states, and messages covered by this model is defined below in [Table 4.125](#):

Element	SIG Model ID	States	Messages	Rx	Tx
Primary	0x0002	Current Fault (see Section 4.2.15.1)	Health Current Status		M
		Registered Fault (see Section 4.2.15.2)	Health Fault Get	M	
			Health Fault Clear	M	
			Health Fault Clear Unacknowledged	M	
			Health Fault Status		M
			Health Fault Test	M	
			Health Fault Test Unacknowledged	M	
		Health Period (see Section 4.2.16)	Health Period Get	M	
			Health Period Set	M	
			Health Period Set Unacknowledged	M	
			Health Period Status		M
		Attention Timer (see Section 4.2.9)	Health Attention Get	M	
			Health Attention Set	M	
			Health Attention Set Unacknowledged	M	
			Health Attention Status		M

Table 4.125: Health Server elements, states, messages

4.4.3.2 Behavior

This section describes behaviors for states and messages for this server model.

4.4.3.2.1 Current Fault state

When the value of a Publish Period state is non-zero, and a Current Fault Fault Array (see Section [4.2.15.1](#)) for any Company ID contains no records, an unsolicited Health Current Status message with the

Company ID field set to one of the Company IDs supported by the Health Fault state and an empty FaultArray field shall be published every number of seconds as defined by the value of the Publish Period state. It is recommended that in this case the Company ID is set to the value of the CID field of the Composition Data state (see Section 4.2.1).

When the value of a Publish Period state is non-zero, and a Current Fault Fault Array (see Section 4.2.15.1) for at least one Company ID contains records, an unsolicited Health Current Status message set to the value of that Company ID and the FaultArray field containing a sequence of faults representing a sequence of faults in the Current Fault Fault Array (see Section 4.2.15.1) shall be published every number of seconds as defined by the value of the Publish Period divided by the value represented by the Health Fast Period Divisor state.

4.4.3.2.2 *Registered Fault state*

When an element receives a Health Fault Get message with the Company ID field that successfully identifies Health Fault state, it shall respond with a Health Fault Status message with the Company ID field set to the value as set in the incoming message, the Test ID field set to the ID of the most recently performed test for identified state, and the FaultArray field containing a sequence of faults representing a sequence of faults in the Registered Fault FaultArray (see Section 4.2.15.2).

When an element receives a Health Fault Test message with the Company ID field that successfully identified Health Fault state, it shall perform a test indicated by the Test ID and Company ID fields and respond with a Health Fault Status message with the Company ID field set to the value as set in the incoming message, the Test ID field set to the ID of the performed test, and a FaultArray field containing a sequence of faults representing a sequence of faults in the Registered Fault FaultArray (see Section 4.2.15.2).

When an element receives a Health Fault Test Unacknowledged message with the Company ID field that successfully identified Health Fault state, it shall perform a test indicated by the Test ID and Company ID fields.

When an element receives a Health Fault Clear message with the Company ID field that successfully identifies Health Fault state, it shall clear the identified Registered Fault state and respond with a Health Fault Status message with the Company ID field set to the values set in the incoming message, and an empty FaultArray field.

When an element receives a Health Fault Clear Unacknowledged message with the Company ID field that successfully identifies Health Fault state, it shall clear the identified Registered Fault state.

When an Element receives a Health Fault Get, or a Health Fault Test, or a Health Fault Test Unacknowledged, or a Health Fault Clear, or a Health Fault Clear Unacknowledged message that is not successfully processed (i.e. the Company ID field that does not identify any Health Fault state present in the node), it shall ignore the message.

4.4.3.2.3 *Health Period states*

When an element receives a Health Period Get message, it shall respond with a Health Period Status message with the FastPeriodDivisor field set to the current Health Fast Period Divisor state.



When an element receives a Health Period Set message, it shall set the Health Fast Period Divisor state to the value of the FastPeriodDivisor field, and respond with a Health Period Status message with the FastPeriodDivisor field set to the current Health Fast Period Divisor state.

When an element receives a Health Period Set Unacknowledged message, it shall set the Health Fast Period Divisor state to the value of the FastPeriodDivisor field.

4.4.3.2.4 Attention Timer state

When an element receives a Health Attention Get message, it shall respond with a Health Attention Status message with the Attention field set to the current Attention Timer state.

When an element receives a Health Attention Set message, it shall set the Attention Timer state to the value of the Attention field of the message and respond with a Health Attention Status message with the Attention field set to the current Attention Timer state.

When an element receives a Health Attention Set Unacknowledged message, it shall set the Attention Timer state to the value of the Attention field of the message.

An unsolicited Health Attention Status message with the Attention field set to the current Attention Timer state may be sent at any time.

4.4.4 Health Client model

4.4.4.1 Description

The Health Client is a root model (i.e., it does not extend any other models).

If supported, the Health Client model shall be supported by a primary element and may be supported by any secondary elements. The application-layer security on the model is using application keys.

The model defines the elements and procedures listed in [Table 4.126](#) below.

Element	SIG Model ID	Procedure	Messages	Rx	Tx
Primary	0x0003	Current Fault	Current Health Status	M	
		Registered Fault	Health Fault Get		M
			Health Fault Clear		M
			Health Fault Clear Unacknowledged		M
			Health Fault Status	M	
			Health Fault Test		M
			Health Fault Test Unacknowledged		M
		Health Period	Health Period Get		M
			Health Period Set		M



Element	SIG Model ID	Procedure	Messages	Rx	Tx
			Health Period Set Unacknowledged		M
			Health Period Status	M	
		Attention Timer	Health Attention Get		M
			Health Attention Set		M
			Health Attention Set Unacknowledged		M
			Health Attention Status	M	

Table 4.126: Health Client procedures and messages

4.4.4.2 Behavior

This section describes behaviors for procedures and messages for this client model.

An element can send any Health Client message at any time to query or change a state of a peer element.

4.4.4.2.1 Current Fault procedure

Upon receiving a Health Current Status message, a Health Client can determine the Current Fault state of a Health Server.

4.4.4.2.2 Registered Fault procedure

To determine the Registered Fault state identified by Company ID of a Health Server, a Health Client shall send a Health Fault Get message. The response is a Health Fault Status message that contains the Registered Fault state.

To execute a self-test identified by a Test ID and Company ID for a given element and determine the Registered Fault state identified by Company ID of a Health Server with acknowledgment, a Health Client shall send a Health Fault Test message. The response is a Health Fault Status message that contains the Registered Fault state identified by Company ID.

To execute a self-test identified by a Test ID and Company ID for a given element without acknowledgment, a Health Client shall send a Health Fault Test Unacknowledged message.

To clear the Registered Fault state identified by Company ID of a Health Server without acknowledgment, a Health Client shall send a Health Fault Clear Unacknowledged message.

To clear the Registered Fault state identified by Company ID of a Health Server with acknowledgment, a Health Client shall send a Health Fault Clear message. The response is a Health Fault Status message that contains the identified Registered Fault state.

Upon receiving a Health Fault Status message, a Health Client can determine the Registered Fault state of a Health Server.



4.4.4.2.3 Health Period procedure

To determine the Health Fast Period Divisor state of a Health Server, a Health Client shall send a Health Period Get message. The response is a Health Period Status message that contains the Health Fast Period Divisor state.

To set the Health Fast Period Divisor state of a Health Server without acknowledgment, a Health Client shall send a Health Period Set Unacknowledged message.

To reliably set the Health Fast Period Divisor state of a Health Server, a Health Client shall send a Health Period Set message. The response is a Health Period Status message that contains the Health Fast Period Divisor state.

Upon receiving a Health Period Status message, a Health Client can determine the Health Fast Period Divisor state of a Health Server.

4.4.4.2.4 Attention Timer procedure

To determine the Attention Timer state of a Health Server, a Health Client shall send a Health Attention Get message. The response is a Health Attention Status message that contains the Attention Timer state.

To set the Attention Timer state of a Health Server with acknowledgment, a Health Client shall send a Health Attention Set message. The response is a Health Attention Status message that contains the Attention Timer state.

To set the Attention Timer state of a Health Server without acknowledgment, a Health Client shall send a Health Attention Set Unacknowledged message.

Upon receiving a Health Attention Status message, a Health Client can determine the current Attention Timer state of a Health Server.

4.4.5 Summary of SIG Model IDs

Table 4.127 below provides a summary of SIG Model IDs defined within this specification. For a complete list, refer to the Assigned Numbers page [4].

Model Name	SIG Model ID
Configuration Server	0x0000
Configuration Client	0x0001
Health Server	0x0002
Health Client	0x0003

Table 4.127: Summary of SIG Model IDs



5 Provisioning

Provisioning is a process of adding an unprovisioned device to a mesh network, managed by a Provisioner. A Provisioner provides the unprovisioned device with provisioning data that allows it to become a mesh node. The provisioning data includes a network key, the current IV Index, and the unicast address for each element.

A Provisioner is typically a smart phone or other mobile computing device. Although only a single Provisioner is required on a network to do provisioning, multiple Provisioners may be used. The method to share cached data and coordinate across multiple Provisioners is implementation specific.

To provision a device, the provisioning bearer must be established between a Provisioner and a device. A device can be identified to a Provisioner by its Device UUID and other supplementary information that may also be provided.

After the provisioning bearer is established, the Provisioner establishes a shared secret with the device using an Elliptic Curve Diffie-Hellman (ECDH) protocol. It then authenticates the device using OOB information that is specific to that device. Such OOB information may include a public key of the device, a long secret, the requirement to input a value into the device, or the requirement to output a value on that device. Such OOB information also enables the authentication of that device. Once the device has been authenticated, the provisioning data is transmitted to the device encrypted with a key derived from that shared secret. The device key is derived from the ECDHSecret and ProvisioningSalt.

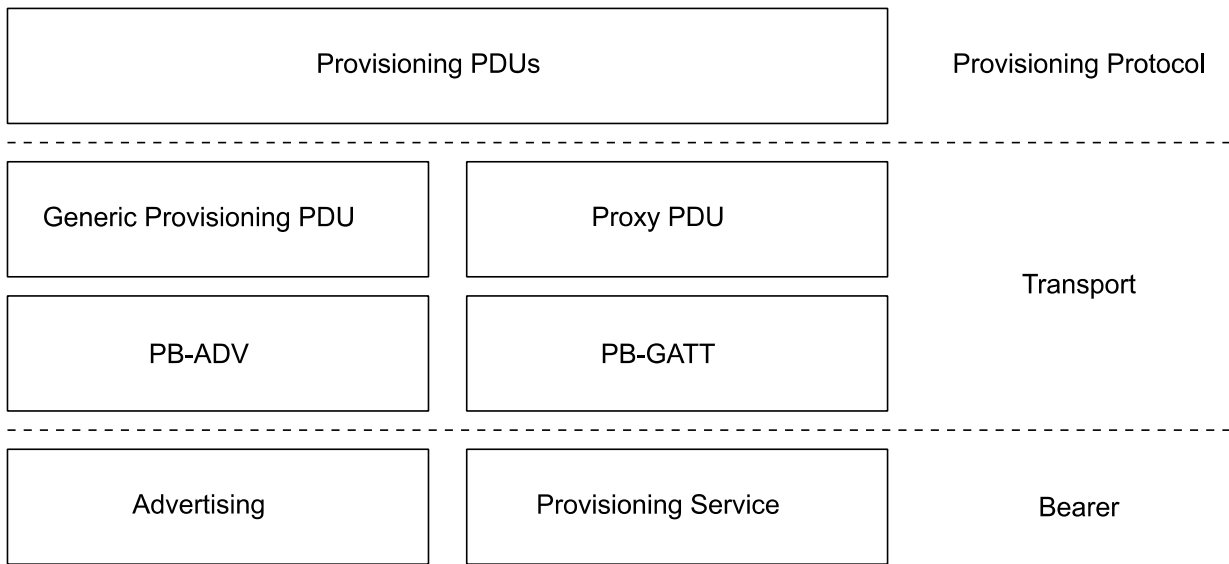


Figure 5.1: Provisioning protocol stack

Provisioning uses a layered architecture, illustrated by [Figure 5.1](#). Provisioning of a device is done using the provisioning protocol that sends provisioning PDUs. The provisioning PDUs are transmitted to an unprovisioned device using a Generic Provisioning layer or Proxy protocol layer. These layers define how the provisioning PDUs are transmitted as transactions that can be segmented and reassembled. These transactions are sent over a provisioning bearer. The provisioning bearers define how sessions are



established such that the transactions from the generic provisioning layer can be delivered to a single device. Finally, at the bottom of the provisioning architecture are the bearers.

5.1 Endianness

Unless stated otherwise, all multiple-octet numeric values in this layer shall be “big endian”, as described in Section 3.1.1.1.

5.2 Provisioning bearer layer

A provisioning bearer layer enables the transportation of Provisioning PDUs between a Provisioner and an unprovisioned device. Two provisioning bearers are defined:

- PB-ADV (see Section 5.2.1)
- PB-GATT (see Section 5.2.2)

An unprovisioned device may support PB-ADV and may support PB-GATT. It is strongly recommended to support PB-ADV and PB-GATT.

A Provisioner shall support at least one of PB-ADV or PB-GATT. It is strongly recommended to support PB-ADV.

5.2.1 PB-ADV

PB-ADV is a provisioning bearer used to provision a device using Generic Provisioning PDUs (see Section 5.3) over the advertising channels. The provisioning mechanism is session based. An unprovisioned device shall support only one session at a time. There is no such limitation for a Provisioner. A session is established using the Link Establishment procedure (see Section 5.3.2).

The PB-ADV bearer is used for transmitting Generic Provisioning PDUs. The PB-ADV bearer MTU (Maximum Transmission Unit) size is 24 octets.

When using PB-ADV, a Generic Provisioning PDU shall be sent using the PB-ADV AD Type identified by «PB-ADV», as defined in [4].

A device supporting PB-ADV should perform passive scanning with a duty cycle as close to 100% as possible in order to avoid missing any incoming Generic Provisioning PDUs.

The PB-ADV AD Type contains a PB-ADV PDU. The format of this AD Type is defined in Table 5.1.

Field	Size (octets)	Description
Length	1	Length of the AD Type and Contents
AD Type	1	«PB-ADV»
Contents	variable	PB-ADV PDU

Table 5.1: PB-ADV AD Type

Any advertisement using the PB-ADV AD Type shall be non-connectable and non-scannable undirected advertising events. If a node receives a PB-ADV AD Type in a connectable or scannable advertising event, the message shall be ignored.

The format of the PB-ADV PDU is defined in [Table 5.2](#).

Field	Size (octets)	Description
Link ID	4	The identifier of a link
Transaction Number	1	The number for identifying a transaction
Generic Provisioning PDU	1–24	Generic Provisioning PDU being transferred

Table 5.2: PB-ADV PDU format

The Link ID is used to identify a link between two devices.

The Transaction Number field contains a one-octet value used to identify each individual Generic Provisioning PDU sent by the device. When a Provisioning PDU that does not fit in a single PB-ADV PDU is segmented, all segments are sent using the same Transaction Number field value. When a Provisioning PDU is retransmitted, the Transaction Number field is not changed.

Transport specific messages are defined to establish and terminate the link between two devices (see [Section 5.3.1.4](#)).

The following rules shall be implemented when sending a PB-ADV PDU:

When the PB-ADV PDU contains a Provisioning Bearer Control PDU, the Transaction Number field shall be set to 0 and ignored upon reception.

When the Provisioner is sending a Provisioning PDU for the first time over an open provisioning link, it shall start with a Transaction Number field value of 0x00. The Provisioner shall increment the field value by one for each new Provisioning PDU it is sending for the duration of the provisioning link. If the field value has reached 0x7F, it shall wrap to 0x00 on sending the next Provisioning PDU.

When the unprovisioned device is sending a Provisioning PDU for the first time over an open provisioning link, it shall start with a Transaction Number field value of 0x80. The Device shall increment the field value by one for each new Provisioning PDU it is sending for the duration of the provisioning link. If the field value has reached 0xFF, it shall wrap to 0x80 on sending the next Provisioning PDU.

When a device is receiving a Provisioning PDU, it shall set the Transaction Number field to the value of the Transaction Number field of the PB-ADV PDUs being received during the transaction.

When a device is sending a Transaction Acknowledgement PDU, the Transaction Number field shall be set to the value of the Transaction Number field of the PB-ADV PDUs transporting the Provisioning PDU being acknowledged.

5.2.2 PB-GATT

PB-GATT is a provisioning bearer used to provision a device using Proxy PDUs (see [Section 6.3](#)) to encapsulate Provisioning PDUs (see [Section 5.4](#)) within the Mesh Provisioning Service (see [Section 7.1](#)).



PB-GATT is provided for support when a Provisioner does not support PB-ADV due to limitations of the application interfaces.

Note: It is recommended that the connection interval for the connection between a Provisioner and device is between 250 and 1000 milliseconds (implementation specific) to enable very low power operation for the device and allow the device to calculate the Diffie-Hellman shared secret without wasting significant energy to maintain an idle link.

The Mesh Provisioning Server shall be able to receive a single Proxy PDU (see Section 6.3) in a single Write Command ATT PDU.

The Mesh Provisioning Server shall use a single Handle Value Notification ATT PDU to send Provisioning PDUs to a Provisioner.

If the negotiated ATT_MTU is less than a required Proxy PDU size, the transmission of the Mesh Provisioning Data In and Mesh Provisioning Out characteristics always needs to be fragmented and reassembled. Each PDU shall be fully reassembled before processing.

The Mesh Provisioning Server shall be able to receive a Proxy PDU in one or several ATT PDUs. The Mesh Provision Server shall use one or several Handle Value Notification ATT PDUs to send a Proxy PDU to the Provision Client depending on the size of the message and negotiated ATT_MTU.

Mesh Provisioning Data In and Mesh Provisioning Data Out Characteristic Format are using Proxy PDU Format defined in Section 6.3.1.

5.3 Generic Provisioning layer

The Generic Provisioning layer is responsible for transport of Generic Provisioning PDUs over an unreliable connectionless provisioning bearer. This layer also defines Generic Provisioning PDUs.

The Generic Provisioning PDU format consists of a Generic Provisioning Control (GPC) field followed by a variable length Generic Provisioning Payload field as illustrated in Figure 5.2 and defined in Table 5.3.

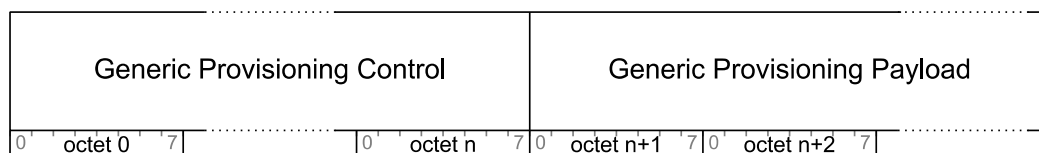


Figure 5.2: Generic Provisioning PDU format

Field	Size (octets)	Description
Generic Provisioning Control	1–17	Generic Provisioning Control field
Generic Provisioning Payload	0–64	Generic Provisioning Payload (segments of the Provisioning PDU)

Table 5.3: Generic Provisioning PDU format

The two least significant bits of the first octet of the Generic Provisioning Control field contain a Generic Provisioning Control Format (GPCF) field that determines the format of the Generic Provisioning Control field. The GPCF field is an enumeration with the values shown in [Table 5.4](#).

Value	Description
0b00	Transaction Start
0b01	Transaction Acknowledgment
0b10	Transaction Continuation
0b11	Provisioning Bearer Control

Table 5.4: Generic Provisioning Control Format field values

The format of the GPC field for each format type is defined in [Section 5.3.1](#).

5.3.1 Generic Provisioning PDU types

5.3.1.1 Transaction Start PDU

The Transaction Start PDU is used to start the transmission of a segmented message. The Generic Provisioning Control field of a Transaction Start PDU is illustrated in [Figure 5.3](#) and shown in [Table 5.5](#).

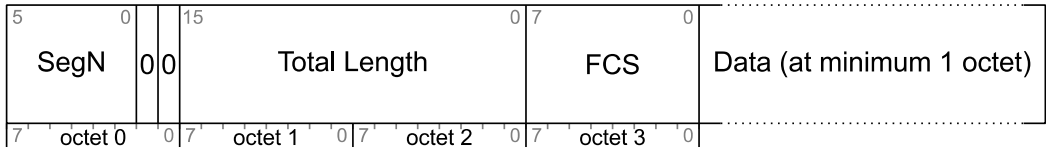


Figure 5.3: Transaction Start PDU

Field	Size (bits)	Description
SegN	6	The last segment number
GPCF	2	0b00 = Transaction Start
TotalLength	16	The number of octets in the Provisioning PDU
FCS	8	Frame Check Sequence of the Provisioning PDU

Table 5.5: Generic Provisioning Control field for Transaction Start PDU

The SegN field shall be set to the last segment number (zero-based) of this transaction.

The GPCF field shall be set to 0b00.

The TotalLength field shall be set to the number of octets in the Provisioning PDU.

When transmitted using PB-ADV, the FCS field is calculated as defined by 3GPP TS 27.010 with the Polynomial ($x^8 + x^2 + x^1 + 1$) and is calculated over the Provisioning PDU only.

The Generic Provisioning Payload shall contain segment 0 of the Provisioning PDU.



5.3.1.2 Transaction Acknowledgment PDU

The Transaction Acknowledgment PDU is used to acknowledge a Provisioning PDU. The Generic Provisioning Control field of a Transaction Acknowledgment PDU is illustrated in Figure 5.4 and shown in Table 5.6.

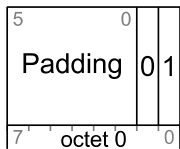


Figure 5.4: Transaction Acknowledgment PDU

Field	Size (bits)	Description
Padding	6	0b000000; all other values Prohibited
GPCF	2	0b01 = Transaction Acknowledgment

Table 5.6: Generic Provisioning Control field for Transaction Acknowledgment PDU

The GPCF field shall be set to 0b01.

The Generic Provisioning Payload is zero length.

5.3.1.3 Transaction Continuation PDU

The Transaction Continuation PDU is used to send additional segments of a Provisioning PDU. The Generic Provisioning Control field of a Transaction Continuation PDU is illustrated in Figure 5.5 and shown in Table 5.7.

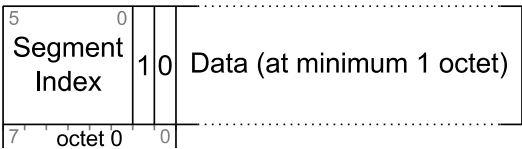


Figure 5.5: Transaction Continuation PDU

Field	Size (bits)	Description
SegmentIndex	6	Segment number of the transaction
GPCF	2	0b10 = Transaction Continuation

Table 5.7: Generic Provisioning Control field for Transaction Continuation PDU

The SegmentIndex field shall be set to the segment number contained within this PDU.

The GPCF field shall be set to 0b10.

The Generic Provisioning Payload shall contain segment SegmentIndex of the Provisioning PDU.



5.3.1.4 Provisioning Bearer Control

The Provisioning Bearer Control PDU is used to manage sessions on bearers that have no inherent session management. The Generic Provisioning Control field of a Provisioning Bearer Control PDU is illustrated in Figure 5.6 and shown in Table 5.8. The Provisioning Bearer Control PDUs are defined in the following sections.

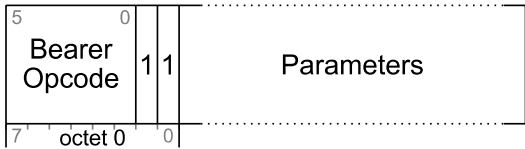


Figure 5.6: Provisioning Bearer Control PDU

Field	Size (bits)	Description
BearerOpcode	6	The opcode for the provisioning bearer control PDUs
GPCF	2	0b11 = Provisioning Bearer Control
Parameters	variable	Parameters defined by each BearerOpcode

Table 5.8: Generic Provisioning Control field for Provisioning Bearer Control PDU

The BearerOpcode values are defined in Table 5.9.

Value	Message	Notes
0x00	Link Open	Open a session on a bearer with a device
0x01	Link ACK	Acknowledge a session on a bearer
0x02	Link Close	Close a session on a bearer
0x03–0x3F	RFU	Reserved for Future Use

Table 5.9: BearerOpcode field values

The GPCF field shall be set to 0b11.

The Generic Provisioning Payload is zero length.

The Parameters of each message are defined in the sections that follow.

5.3.1.4.1 Link Open message

The Link Open message is used to establish a link between a Provisioner and an unprovisioned device. The device shall acknowledge this message with the Link ACK message.

The Parameters field for the Link Open message is defined in Table 5.10 and the message is illustrated in Figure 5.7.

Field	Size (octets)	Description
-------	---------------	-------------



Device UUID	16	This is the Device UUID of the chosen unprovisioned device
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Table 5.10: Parameters field of Link Open message

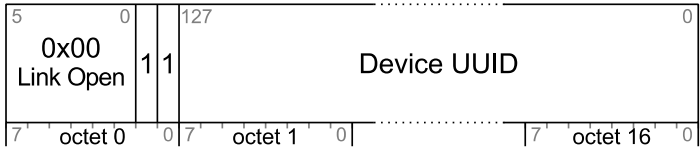


Figure 5.7: Link Open message format

5.3.1.4.2 Link ACK message

The Link Ack message is sent to acknowledge the receipt of the Link Open message.

There are no Parameters for this message.

The Link Ack message is illustrated in Figure 5.8.

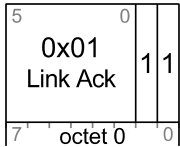


Figure 5.8: Link Ack message format

5.3.1.4.3 Link Close message

The Link Close message is used to close a link. Since this message is not acknowledged, the sender shall repeat this message at least three times. Both sides of the link may send this message. This message shall be accepted and processed regardless of the setting of the Reason field.

The Parameters field for the Link Close message is defined in Table 5.11 and the message is illustrated in Figure 5.9.

Field	Size (octets)	Description
Reason	1	The reason for closing the link

Table 5.11: Parameters field of Link Close message

The Reason field values are defined in Table 5.12.

Value	Reason	Notes
0x00	Success	The provisioning was successful
0x01	Timeout	The provisioning transaction timed out
0x02	Fail	The provisioning failed
0x03–0xFF	Unrecognized	Unrecognized reason that may be defined in the future.

Table 5.12: Reason field values



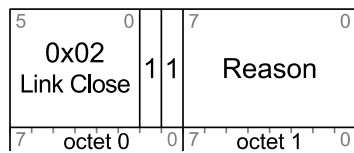


Figure 5.9: Link Close message format

5.3.2 Link Establishment procedure

The Link Establishment procedure is used to establish a session for a bearer that does not have inherent session management. A session is identified by using a Link ID that is static for the duration of the session and shall be randomly generated to prevent collisions between sessions.

A link is established between a Provisioner and an unprovisioned device for sending provisioning messages. The unprovisioned device is identified by a Device UUID (see Section 3.10.3).

The Provisioner shall scan for unprovisioned devices. Upon receiving an Unprovisioned Device beacon, the Provisioner may establish a link with the device identified by the Device UUID.

The link is open for the device when the device sends a Link ACK for the Link Open message. The link is open for the Provisioner when a Link ACK is received with the Link ID equal to the Link ID sent in the Link Open message. The device is being provisioned when the link is open and the device has received any Provisioning PDU.

When the link is not open, and the device receives a Link Open message, then the device shall accept this message by replying with a Link ACK message with the same Link ID set in the PB-ADV PDU. When the link is open, and the device is not being provisioned, and the device receives a Link Open message with the same Link ID, then the device shall reply with a Link ACK message with the same Link ID set in the PB-ADV PDU.

The device shall start the link timer, set to 60 seconds, when the link is open. When the link timer expires, then the device shall close the link. When the device receives any Provisioning PDU or a Link Close message, then the device shall cancel the link timer.

To open a link, the Provisioner shall start the link establishment timer, set to 60 seconds, and then shall start sending Link Open messages. The Provisioner may abort this procedure at any time. The Link Open message contains the Device UUID of the device. On PB-ADV, the PB-ADV PDU format includes a Link ID field.

When the link establishment timer expires, the link is considered not open and the procedure may be restarted. When the link is open, the Provisioner cancels the link establishment timer.

The link may be closed at any time after link establishment by sending the Link Close message. Either side of the link may send the Link Close message.

The Link Open, Link ACK, and Link Close messages are defined in Section 5.3.1.4.

The message sequence for establishment of a link by ID between a Provisioner and an unprovisioned device is illustrated by Figure 5.10 below.

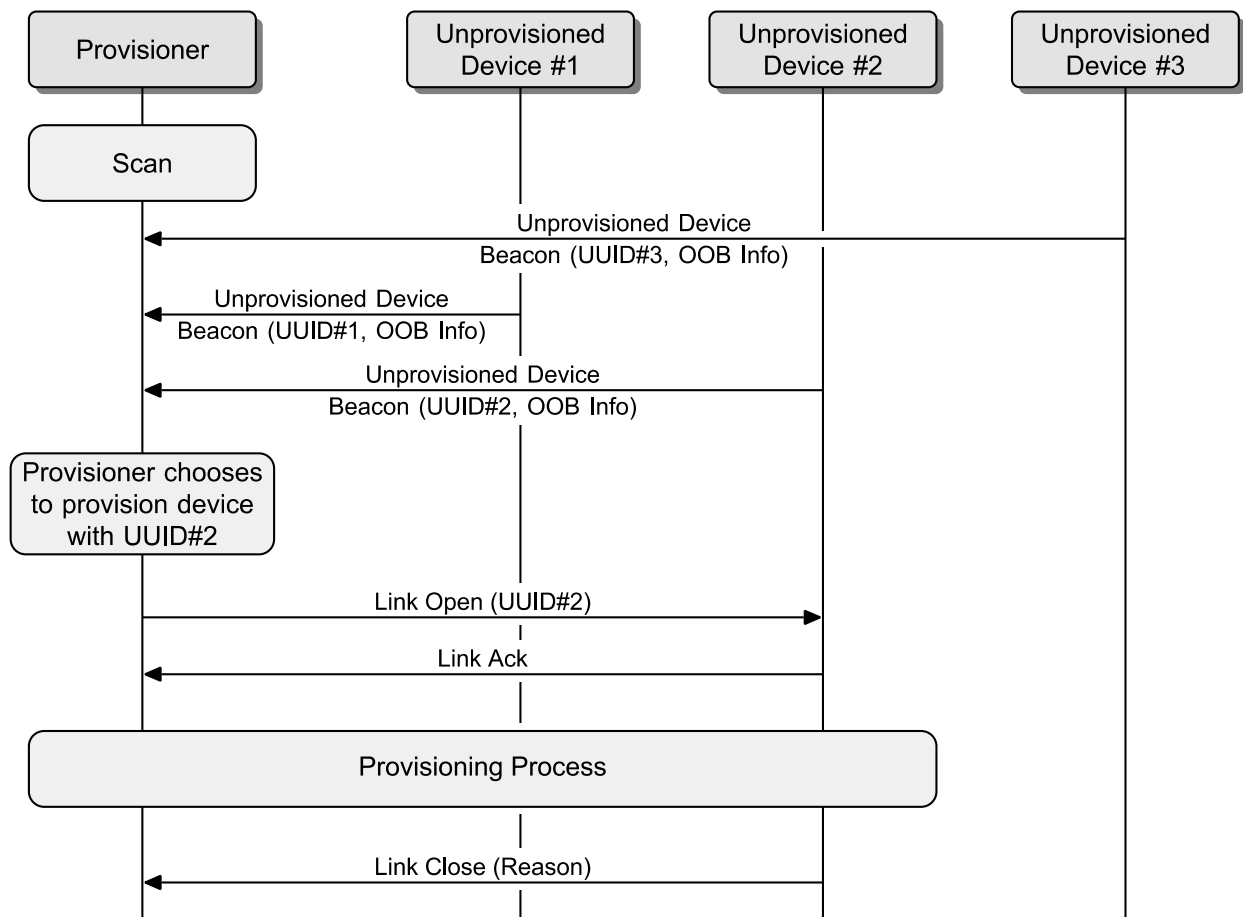


Figure 5.10: Establishment of Link by ID between a Provisioner and an unprovisioned device

5.3.3 Generic Provisioning behavior

Each Generic Provisioning PDU shall be sent after a random delay between 20 and 50 milliseconds.

Each Provisioning PDU (see Section 5.4) is transmitted as a separate transaction. A transaction may be composed of one or more segments.

The number of segments required to send a Provisioning PDU is determined by the size of the Provisioning PDU. Segments are indexed from 0 to 63. Segment 0 shall be sent using a Transaction Start PDU. All other segments shall be sent using a Transaction Continuation PDU. Each segment of the Provisioning PDU is placed into the Generic Provisioning Payload field of the respective Generic Provisioning PDU.

Each bearer has its own constraints on the maximum size of a Generic Provisioning PDU that can be transmitted by that bearer. Each Generic Provisioning PDU shall be the length of the full MTU for that bearer, except for the last segment of a transaction.

The sender shall send all segments of a transaction in sequence. If the sender does not receive a Transaction Acknowledgment message, the sender shall retransmit all segments of a transaction.

If the sender receives a Transaction Acknowledgment message, then the transaction has completed.

If the sender receives a message with other PDU types, then the message shall be ignored.

If the sender does not receive a Transaction Acknowledgment message within 30 seconds after sending the first message in a transaction, the sender shall cancel the transaction, cancel the provisioning process and close the link.

The receiver shall determine the number of segments for a transaction from the Transaction Start PDU.

On the PB-ADV bearer, when the receiver has received all segments of a transaction, the receiver shall calculate the FCS for the received Provisioning PDU, and if it matches the FCS field in the Transaction Start PDU, it shall send a Transaction Acknowledgment PDU after a random delay between 20 and 50 milliseconds.

When a Transaction Acknowledgment PDU has been sent for a given transaction and another segment of the same transaction has been received, another Transaction Acknowledgment PDU shall be sent and the received segment shall be ignored.

5.4 Provisioning protocol

This section defines requirements for Provisioning PDUs, behavior, and security.

5.4.1 Provisioning PDUs

The Provisioning PDUs are used to communicate between a Provisioner and a device.

The first octet of the Provisioning PDU is the Type field and defines the format of the Parameters of the Provisioning PDU.

The Provisioning PDU format is defined in [Table 5.13](#) and illustrated in [Figure 5.11](#).

Field	Size (bits)	Description
Padding	2	0b00. All other values are Prohibited
Type	6	Provisioning PDU Type values (see Table 5.14)
Parameters	variable	Message parameters

Table 5.13: Provisioning PDU format

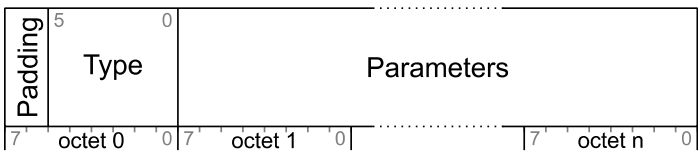


Figure 5.11: Provisioning PDU format

The Provisioning PDU Type values are defined in [Table 5.14](#).

Type	Name	Description
0x00	Provisioning Invite	Invites a device to join a mesh network
0x01	Provisioning Capabilities	Indicates the capabilities of the device
0x02	Provisioning Start	Indicates the provisioning method selected by the Provisioner based on the capabilities of the device
0x03	Provisioning Public Key	Contains the Public Key of the device or the Provisioner
0x04	Provisioning Input Complete	Indicates that the user has completed inputting a value
0x05	Provisioning Confirmation	Contains the provisioning confirmation value of the device or the Provisioner
0x06	Provisioning Random	Contains the provisioning random value of the device or the Provisioner
0x07	Provisioning Data	Includes the assigned unicast address of the primary element, a network key, NetKey Index, Flags and the IV Index
0x08	Provisioning Complete	Indicates that provisioning is complete
0x09	Provisioning Failed	Indicates that provisioning was unsuccessful
0x0A–0xFF	RFU	Reserved for Future Use

Table 5.14: Provisioning PDU types

5.4.1.1 Provisioning Invite

A Provisioner sends this PDU to indicate to the device that the provisioning process is starting. The format of the parameters for this PDU is defined in [Table 5.15](#).

Field	Size (octets)	Notes
Attention Duration	1	Attention Timer state (See Section 4.2.9)

Table 5.15: Provisioning Invite PDU parameters format

5.4.1.2 Provisioning Capabilities

The device sends this PDU to indicate its supported provisioning capabilities to a Provisioner. The format of the parameters for this PDU is defined in [Table 5.16](#).

Field	Size (octets)	Notes
Number of Elements	1	Number of elements supported by the device (Table 5.17)
Algorithms	2	Supported algorithms and other capabilities (see Table 5.18)
Public Key Type	1	Supported public key types (see Table 5.19)
Static OOB Type	1	Supported static OOB Types (see Table 5.20)
Output OOB Size	1	Maximum size of Output OOB supported (see Table 5.21)



Field	Size (octets)	Notes
Output OOB Action	2	Supported Output OOB Actions (see Table 5.22)
Input OOB Size	1	Maximum size in octets of Input OOB supported (see Table 5.23)
Input OOB Action	2	Supported Input OOB Actions (see Table 5.24)

Table 5.16: Provisioning Capabilities PDU parameters format

The Number of Elements values are defined in [Table 5.17](#).

Value	Description
0x00	Prohibited
0x01–0xFF	The number of elements supported by the device

Table 5.17: Number of Elements field values

The Algorithm values are defined in [Table 5.18](#).

Bit	Description
0	FIPS P-256 Elliptic Curve
1–15	Reserved for Future Use

Table 5.18: Algorithms field values

At least one Algorithm shall be supported by a device.

The Public Key Type values are defined in [Table 5.19](#).

Bit	Description
0	Public Key OOB information available
1–7	Prohibited

Table 5.19: Public Key Type field values

The size of the Public Key OOB information is determined by the selected Algorithm.

The Static OOB Type values are defined in [Table 5.20](#).

Bit	Description
0	Static OOB information available
1–7	Prohibited

Table 5.20: Static OOB Type field values

The maximum size of the Static OOB information is 16 octets.

The Output OOB Size defines the number of digits that can be output (e.g., displayed or spoken) when the value Output Numeric is set and Output Alphanumeric is not set in the Output OOB Action field (see

[Table 5.22](#)). The Output OOB Size defines the number of digits and uppercase letters that can be output when the value Output Numeric is not set and Output Alphanumeric is set in the Output OOB Action field. The Output OOB Size defines the number of digits and uppercase letters that can be output when the value Output Numeric is set and Output Alphanumeric is set in the Output OOB Action field. The Output OOB Size values are defined in [Table 5.21](#).

Value	Description
0x00	The device does not support output OOB
0x01–0x08	Maximum size of Output OOB supported by the device
0x09–0xFF	Reserved for Future Use

Table 5.21: Output OOB Size field values

The Output OOB Action values are defined in [Table 5.22](#).

Bit	Description	Data Type
0	Blink	Numeric
1	Beep	Numeric
2	Vibrate	Numeric
3	Output Numeric	Numeric
4	Output Alphanumeric	Alphanumeric
5–15	Reserved for Future Use	n/a

Table 5.22: Output OOB Action field values

The Input OOB Size defines the number of digits that can be entered when the value Input Numeric is set and Input Alphanumeric is not set in the Input OOB Action field (see [Table 5.24](#)). The Input OOB Size defines the number of digits and uppercase letters that can be entered when the value Input Numeric is not set and Input Alphanumeric is set in the Input OOB Action field. The Input OOB Size defines the number of digits and uppercase letters that can be entered when the value Input Numeric is set and Input Alphanumeric is set in the Input OOB Action field. The Input OOB Size values are defined in [Table 5.23](#).

Value	Description
0x00	The device does not support Input OOB
0x01–0x08	Maximum size of Input OOB supported by the device
0x09–0xFF	Reserved for Future Use

Table 5.23: Input OOB Size field values

The Input OOB Actions are defined in [Table 5.24](#).

Bit	Description	Data Type
0	Push	Numeric
1	Twist	Numeric

Bit	Description	Data Type
2	Input Numeric	Numeric
3	Input Alphanumeric	Alphanumeric
4–15	Reserved for Future Use	n/a

Table 5.24: Input OOB Action field values

5.4.1.3 Provisioning Start

A Provisioner sends this PDU to indicate the method it has selected from the options in the Provisioning Capabilities PDU. The format of the parameters for this PDU is defined in [Table 5.25](#).

Field	Size (octets)	Notes
Algorithm	1	The algorithm used for provisioning (see Table 5.26)
Public Key	1	Public Key used (see Table 5.27)
Authentication Method	1	Authentication Method used (see Table 5.28)
Authentication Action	1	Selected Output OOB Action (see Table 5.29) or Input OOB Action (see Table 5.31) or 0x00
Authentication Size	1	Size of the Output OOB used (see Table 5.30) or size of the Input OOB used (see Table 5.32) or 0x00

Table 5.25: Provisioning Start PDU parameters format

The Algorithm values are defined in [Table 5.26](#).

Value	Description
0x00	FIPS P-256 Elliptic Curve
0x01–0xFF	Reserved for Future Use

Table 5.26: Algorithm field values

The Public Key values are defined in [Table 5.27](#).

Value	Description
0x00	No OOB Public Key is used
0x01	OOB Public Key is used
0x02–0xFF	Prohibited

Table 5.27: Public Key field values

The Authentication Method values are defined in [Table 5.28](#).

Value	Description
0x00	No OOB authentication is used
0x01	Static OOB authentication is used
0x02	Output OOB authentication is used
0x03	Input OOB authentication is used
0x04–0xFF	Prohibited

Table 5.28: Authentication Method field values

When the Authentication Method 0x00 (Authentication with No OOB) method is used, the Authentication Action field shall be set to 0x00 and the Authentication Size field shall be set to 0x00.

When the Authentication Method 0x01 (Authentication with Static OOB) method is used, the Authentication Size shall be set to 0x00 and the Authentication Action field shall be set to 0x00.

When the Authentication Method 0x02 (Authentication with Output OOB) is used, the values defined in [Table 5.29](#) and [Table 5.30](#) shall be used to determine the Authentication Action and the Authentication Size.

The Output OOB Action values for the Authentication Size Action field are defined in [Table 5.29](#).

Value	Description
0x00	Blink
0x01	Beep
0x02	Vibrate
0x03	Output Numeric
0x04	Output Alphanumeric
0x05–0xFF	Reserved for Future Use

Table 5.29: Output OOB Action values for the Authentication Action field

The Output OOB Size for the Authentication Size field values are defined in [Table 5.30](#).

Value	Description
0x00	Prohibited
0x01–0x08	The Output OOB Size to be used
0x09–0xFF	Reserved for Future Use

Table 5.30: Output OOB Size values for the Authentication Size field

When the Authentication Method 0x03 (Authentication with Input OOB) method is used, the values defined in [Table 5.31](#) and [Table 5.32](#) shall be used to determine the Authentication Action and the Authentication Size.



The Input OOB Action values for the Authentication Action field are defined in [Table 5.31](#).

Value	Description
0x00	Push
0x01	Twist
0x02	Input Numeric
0x03	Input Alphanumeric
0x04–0xFF	Reserved for Future Use

Table 5.31: Input OOB Action values for the Authentication Action field

The Input OOB Size values for the Authentication Size field are defined in [Table 5.32](#).

Value	Description
0x00	Prohibited
0x01–0x08	The Input OOB size to be used
0x09–0xFF	Reserved for Future Use

Table 5.32: Input OOB Size values for the Authentication Size field

5.4.1.4 Provisioning Public Key

This Provisioner sends this PDU to deliver the public key to be used in the ECDH calculations. The format of the parameters for this PDU is defined in [Table 5.33](#).

Field	Size (octets)	Notes
Public Key X	32	The X component of public key for the FIPS P-256 algorithm
Public Key Y	32	The Y component of public key for the FIPS P-256 algorithm

Table 5.33: Provisioning Public Key PDU Parameters Format

5.4.1.5 Provisioning Input Complete

The device sends this PDU when the user completes the input operation.

There are no parameters for this PDU.

5.4.1.6 Provisioning Confirmation

The Provisioner or the device sends this PDU to the peer to confirm the values exchanged so far including the OOB Authentication value and the random number that has yet to be exchanged. The format of the parameters for this PDU is defined in [Table 5.34](#).

Field	Size (octets)	Notes
Confirmation	16	The values exchanged so far including the OOB Authentication value

Table 5.34: Provisioning Confirmation PDU Parameters Format

5.4.1.7 Provisioning Random

A Provisioner or device sends this PDU to enable the peer device to validate the confirmation. The format of the parameters for this PDU is defined in [Table 5.35](#).

Field	Size (octets)	Notes
Random	16	The final input to the confirmation

Table 5.35: Provisioning Random PDU parameters format

5.4.1.8 Provisioning Data

A Provisioner sends this PDU to deliver provisioning data to the device. The format of the parameters for this PDU is defined in [Table 5.36](#).

Field	Size (octets)	Notes
Encrypted Provisioning Data	25	An encrypted and authenticated network key, NetKey Index, Key Refresh Flag, IV Update Flag, current value of the IV Index, and unicast address of the primary element (see Section 5.4.2.5)
Provisioning Data MIC	8	PDU Integrity Check value

Table 5.36: Provisioning Data PDU parameters format

5.4.1.9 Provisioning Complete

The device sends this PDU to indicate that it has successfully received and processed the provisioning data.

There are no parameters for this PDU.

5.4.1.10 Provisioning Failed

The device sends this PDU if it fails to process a received provisioning protocol PDU. The format of the parameters for this PDU is defined in [Table 5.37](#).

Field	Size (octets)	Notes
Error Code	1	This represents a specific error in the provisioning protocol encountered by a device

Table 5.37: Provisioning Failed PDU parameters format



The Provisioning Error Codes are defined in [Table 5.38](#).

Value	Name	Description
0x00	Prohibited	Prohibited
0x01	Invalid PDU	The provisioning protocol PDU is not recognized by the device
0x02	Invalid Format	The arguments of the protocol PDUs are outside expected values or the length of the PDU is different than expected
0x03	Unexpected PDU	The PDU received was not expected at this moment of the procedure
0x04	Confirmation Failed	The computed confirmation value was not successfully verified
0x05	Out of Resources	The provisioning protocol cannot be continued due to insufficient resources in the device
0x06	Decryption Failed	The Data block was not successfully decrypted
0x07	Unexpected Error	An unexpected error occurred that may not be recoverable
0x08	Cannot Assign Addresses	The device cannot assign consecutive unicast addresses to all elements
0x09–0xFF	RFU	Reserved for Future Use

Table 5.38: Provisioning error codes

5.4.2 Provisioning behavior

Provisioning is performed using a five-step process: beaconing, invitation, exchanging public keys, authentication, and distribution of the provisioning data, as illustrated by [Figure 5.12](#).



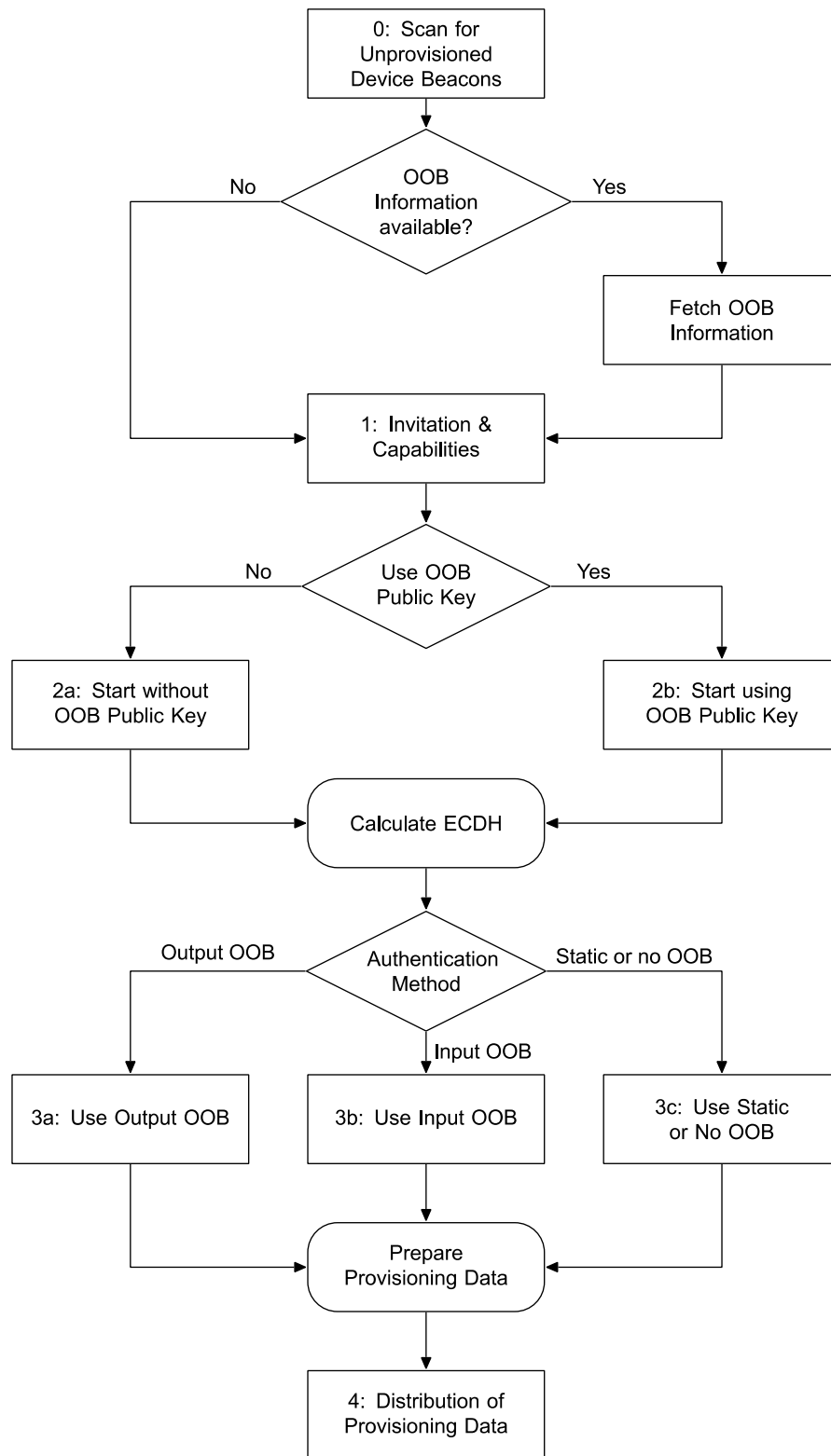


Figure 5.12: Provisioning behavior



5.4.2.1 Beaconsing

A device that supports PB-ADV, has not been provisioned, and is not in the process of being provisioned, shall advertise the Unprovisioned Device beacon, as defined in Section 3.9.2, otherwise a device shall not advertise the Unprovisioned Device beacon. When a device has not been provisioned, it is recommended to use anonymous advertising [2], a non-resolvable private address, or a resolvable private address. This beacon may indicate availability of OOB data that allows a Provisioner to prompt the user to collect this OOB data before the next step.

5.4.2.2 Invitation

After establishing a provisioning bearer, a Provisioner shall send a Provisioning Invite PDU and the device shall respond with a Provisioning Capabilities PDU. The Provisioning Invite PDU includes an Attention Duration field, used to determine how long the primary element of the device identifies itself using the Attention Timer, as described in Section 4.2.9. If the provisioning bearer is dropped, the device shall set the Attention Timer state of the primary element to 0x00 (Off). The Provisioning Capabilities PDU includes the information on the number of elements the device supports, the set of security algorithms supported, the availability of its public key using an OOB technology, the ability for this device to output a value to the user, the ability for this device to allow a value to be input by the user, and if the device has a block of OOB data that can be used for authentication.

The message sequence for provisioning invitation is illustrated by Figure 5.13 below.

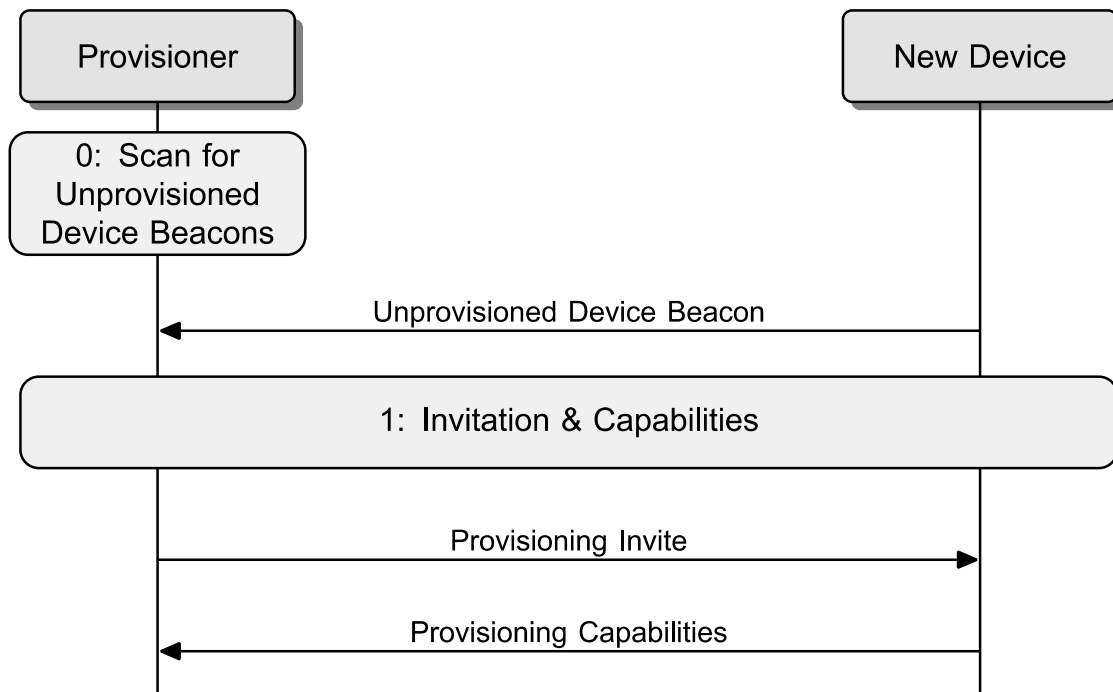


Figure 5.13: Provisioning invitation

5.4.2.3 Exchanging public keys

This step has two possibilities depending on the availability of the unprovisioned device public key at a Provisioner's side. Combined with the three possibilities of the authentication step (see Section 5.4.2.4), there are six possible exchange/authentication paths.

Once the Provisioner has determined that it can provision the device, it shall send a Provisioning Start PDU that details which of the six possible paths that the Provisioner has chosen to use.

Upon receiving the Provisioning Start PDU from the Provisioner, the device shall set the Attention Timer to 0x00.

The Provisioner shall select a single algorithm from those offered to it by the New Device in the Provisioning Capability PDU. If the Provisioner does not understand a bit set in this algorithm bit field, it shall ignore that bit and only select from the algorithms it does understand. The Provisioner should choose the strongest algorithm.

If the public key was not available using an OOB technology, then the public keys are exchanged between the Provisioner and the unprovisioned device. For each exchange, a new key pair shall be generated by the Provisioner and the unprovisioned device.

The device shall send its public key if the key is not delivered OOB.

The message sequence for public key exchange when the unprovisioned device public key is unknown is illustrated by Figure 5.14 below.

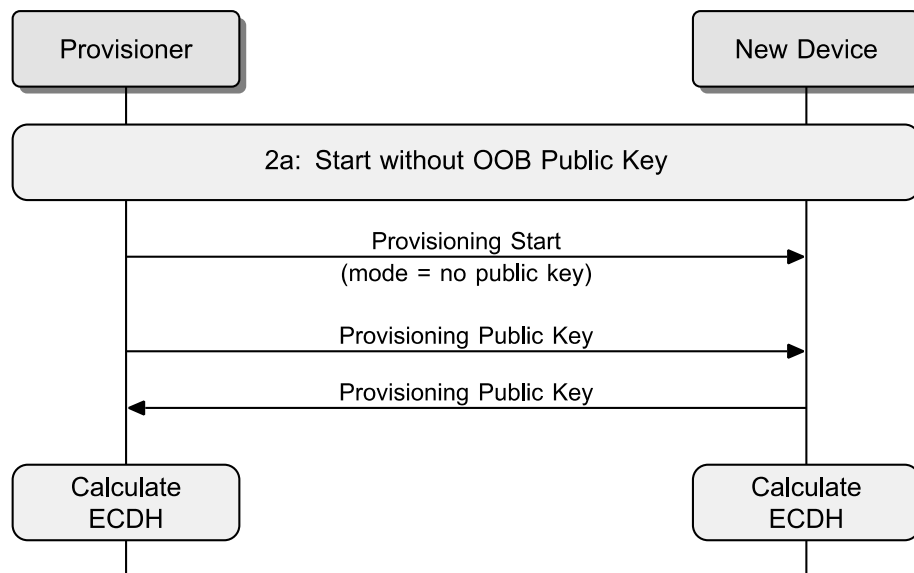


Figure 5.14: Public key exchange when unprovisioned device public key is unknown

Otherwise, if the public key is available via an OOB mechanism, then a new key pair shall be generated by the Provisioner, and the public key of the generated key pair shall be transmitted from the Provisioner to the device, and a static public key shall be read from the device using the appropriate OOB technology.

The message sequence for public key exchange when the unprovisioned device public key is OOB is illustrated by [Figure 5.15](#) below.

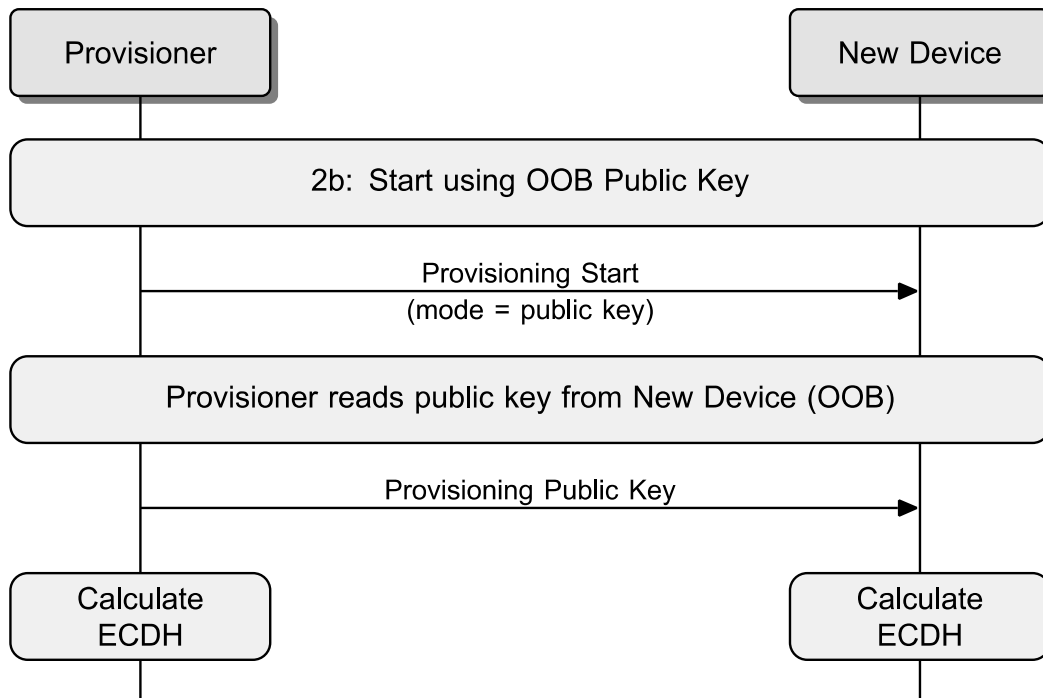


Figure 5.15: Public key exchange when unprovisioned device public key is out-of-band

The Provisioner and the device shall check whether the public key provided by the peer device or obtained OOB is valid (see [Section 5.4.3.1](#)).

When the Provisioner receives an invalid public key, then provisioning fails, and the Provisioner shall act as described in [Section 5.4.4](#). When the device receives an invalid public key, then provisioning fails, and the device shall act as described in [Section 5.4.4](#).

After the public key is known and has been validated, the ECDHSecret shall be computed using the following formula:

$$\text{ECDHSecret} = \text{P-256}(\text{private key, peer public key})$$

After the ECDHSecret is computed, the Provisioner and the unprovisioned device shall delete its private-public key pair that was generated in this step.

5.4.2.4 Authentication

If Output OOB authentication is used, then the Provisioning Start PDU would include a request to output either a single digit or multiple digit value on the device using a prescribed action. Examples of output actions may include making a noise, blinking a light, voice, or displaying symbols on a display.

For example, if the device is a door lock that includes an LED, then it would be possible to use the Output OOB authentication with the action that would blink that LED.

When the Authentication Method 0x02 (Authentication with Output OOB) is used and when Output OOB Action for the Authentication Action value is equal to Blink, Beep, or Vibrate, then the device shall select a random integer between 0 and 10 to the power of the Authentication Size exclusive. That random number shall be output as a sequence of events (e.g., by blinking, beeping, or vibrating with a duty cycle of 500 milliseconds on and 500 milliseconds off) with a gap of at least 3 seconds between sequences to allow the user to determine the end of the sequence. When Output OOB Action for the Authentication Action value is equal to Output Numeric, then the value is output (e.g., displayed or spoken) using a number of digits (i.e., ASCII character codes 0x30-0x39) determined by the Authentication Size value. When Output OOB Action for the Authentication Action value is equal to Output Alphanumeric, then the value is output using a number of ASCII digits and uppercase letters (i.e., ASCII character codes 0x30-0x39 and 0x41-0x5A) determined by the Authentication Size value.

The user of the Provisioner shall input the number observed to authenticate that device.

Once input of the number has been performed, a confirmation exchange followed by a random number exchange is performed. The confirmation values are a cryptographic hash of all the values exchanged so far, the random number that is yet to be revealed, and the number that has been input. Once the random numbers are exchanged, each device can authenticate their peer.

The authentication value from Output OOB, Input OOB, or Static OOB is used in AuthValue for the purpose of computing the confirmation value as described below.

The confirmation value of the Provisioner is computed using:

$$\text{ConfirmationProvisioner} = \text{AES-CMAC}_{\text{ConfirmationKey}} (\text{RandomProvisioner} || \text{AuthValue})$$

The confirmation value of the device is computed using:

$$\text{ConfirmationDevice} = \text{AES-CMAC}_{\text{ConfirmationKey}} (\text{RandomDevice} || \text{AuthValue})$$

Where:

$$\text{ConfirmationKey} = k1(\text{ECDHSecret}, \text{ConfirmationSalt}, \text{"prck"})$$

$$\text{ConfirmationSalt} = s1(\text{ConfirmationInputs})$$

$$\text{ConfirmationInputs} = \text{ProvisioningInvitePDUValue} || \text{ProvisioningCapabilitiesPDUValue} || \text{ProvisioningStartPDUValue} || \text{PublicKeyProvisioner} || \text{PublicKeyDevice}$$

The ProvisioningInvitePDUValue is the value of the Provisioning Invite PDU fields (excluding the opcode) that was sent or received.

The ProvisioningCapabilitiesPDUValue is the value of the Provisioning Capabilities PDU fields (excluding the opcode) that was sent or received.

The ProvisioningStartPDUValue is the value of the Provisioning Start PDU fields (excluding the opcode) that was sent or received.

The PublicKeyProvisioner is the value of the Public Key X and Public Key Y fields from the Public Key PDU that was sent by the Provisioner.



The **PublicKeyDevice** is the value of the Public Key X and Public Key Y fields from the Public Key PDU that was sent by the Device or from the delivered OOB public key.

RandomProvisioner is a string of random bits generated by the Provisioner's random number generator. The random number generator shall be compatible with the requirements in Volume 2, Part H, Section 2 of the Core Specification [1].

RandomDevice is a string of random bits generated by the device's random number generator. The random number generator shall be compatible with the requirements in Volume 2, Part H, Section 2 of the Core Specification [1].

The **AuthValue** is a 128-bit value. The computation of **AuthValue** depends on the data type of the Output OOB Action, Input OOB Action, or Static OOB Type that is used.

If the data type is Binary, the **AuthValue** is an array of octets. If the value is shorter than 128 bits, the remaining bits shall be set to 0.

For example, if the value is [0x12, 0x34, 0x56], the **AuthValue** is an array consisting of [0x12, 0x34, 0x56, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00].

If the data type is Numeric, the number shall be represented as an unsigned 128-bit value.

If the data type is Alphanumeric, the **AuthValue** shall be a concatenation of ASCII codes of the characters.

For example, if the Authentication with Output OOB method is used with Output OOB Action as Blink and value outputted is 5, then the **AuthValue** shall be 0x00000000000000000000000000000005. The **AuthValue** is then encoded as defined in Section 5.1 in order to compute confirmation values, resulting in an array consisting of [0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x05].

For example, if the Authentication with Output OOB method is used with Output OOB Action as Display Number and the displayed number is 019655, then the **AuthValue** shall be 0x000000000000000000000000000000CC7. The **AuthValue** is then encoded as defined in Section 5.1 in order to compute confirmation values, resulting in an array consisting of [0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x4C, 0xC7].

For example, if the Authentication with Output OOB method is used with Output OOB Action as Display String and the displayed string is "123ABC", then the **AuthValue** shall be 0x31323341424300000000000000000000, resulting in an array consisting of [0x31, 0x32, 0x33, 0x41, 0x42, 0x43, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00].

For example, if the Authentication with No OOB method is used, the **AuthValue** shall be set to 0x00000000000000000000000000000000, which means it is not authenticated, resulting in an array consisting of [0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00].

The Provisioner shall send the Provisioning Random PDU after it has received the Provisioning Confirmation PDU. The device shall send the Provisioning Random after verifying the confirmation value against the random number it has received.

The message sequence for authentication with Output OOB is illustrated by [Figure 5.16](#) below.

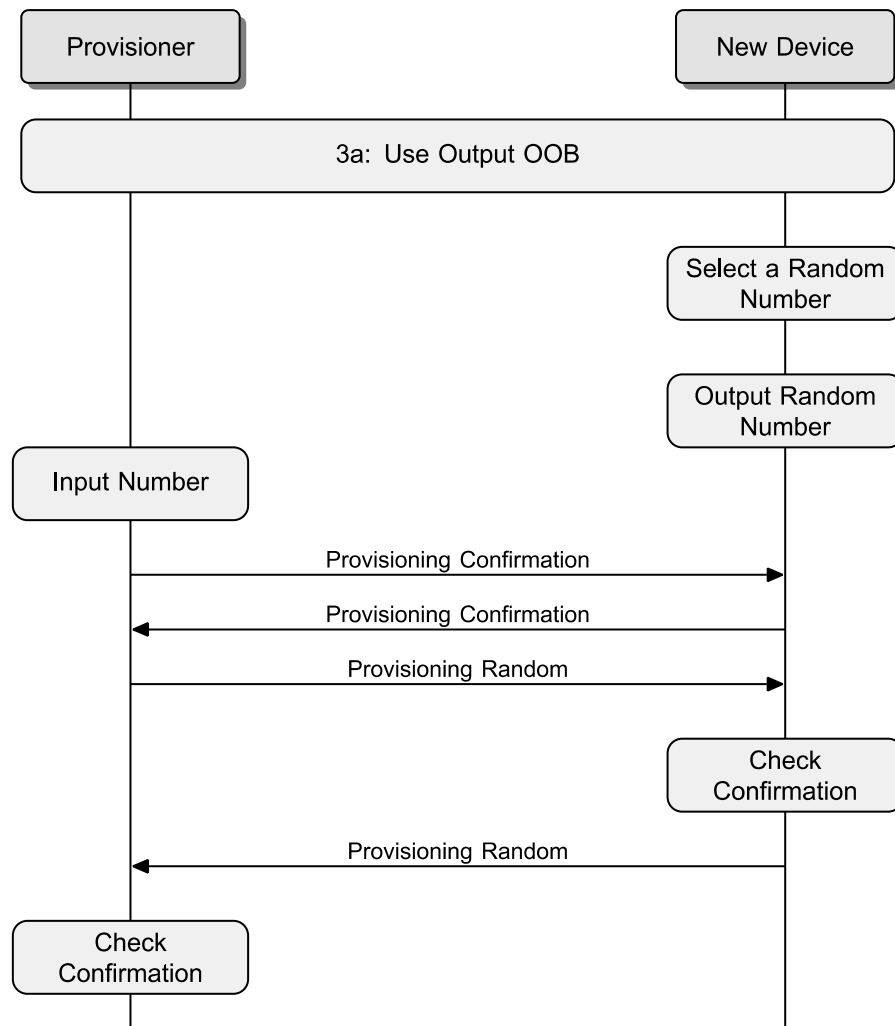


Figure 5.16: Authentication with Output OOB

When the Authentication Method 0x03 (Authentication with Input OOB) method is used and when Input OOB Action for the Authentication Action value is equal to Push, then the Provisioner shall select a random integer between 0 and 10 to the power of the Authentication Size exclusive. That random number shall be input by the number of push actions. When Input OOB Action for the Authentication Action value is equal to Twist, then the Provisioner shall select a random integer between 0 and 10 to the power of the Authentication Size exclusive. That random number shall be input by the number of twist actions until the value on the control has been entered. When Input OOB Action for the Authentication Action value is equal to Input Numeric, the value is input by entering a number of digits (probably using a numeric keyboard) determined by the Authentication Size value. When Input OOB Action for the Authentication Action value is equal to Input Alphanumeric, the value is input by entering a number of ASCII digits and uppercase letters (probably using an alphanumeric keyboard) determined by the Authentication Size value.

The Provisioner shall then prompt the user to input that value into the device using an appropriate action.

When the Input OOB Action for the Authentication Action value is equal to Push or Twist, the value is considered to have been input after no further input actions are detected for more than 5 seconds. When the Input OOB Action for the Authentication Action value is equal to Input Numeric or Input Alphanumeric, the value is considered to have been input locally on that device (e.g., by pressing an Enter key).

For example, a light switch may allow the user to input the random number by pressing a button an appropriate number of times.

Once input of the number has been performed, the device shall send the Provisioning Input Complete PDU to the Provisioner to confirm that the device has an input value. A confirmation exchange followed by a random number exchange is performed. The confirmation values are a cryptographic hash of all the values exchanged so far, the random number that is yet to be revealed, and the number that has been input. Once the random numbers are exchanged, each device can authenticate the peer.

The message sequence for authentication with Input OOB is illustrated by [Figure 5.17](#) below.

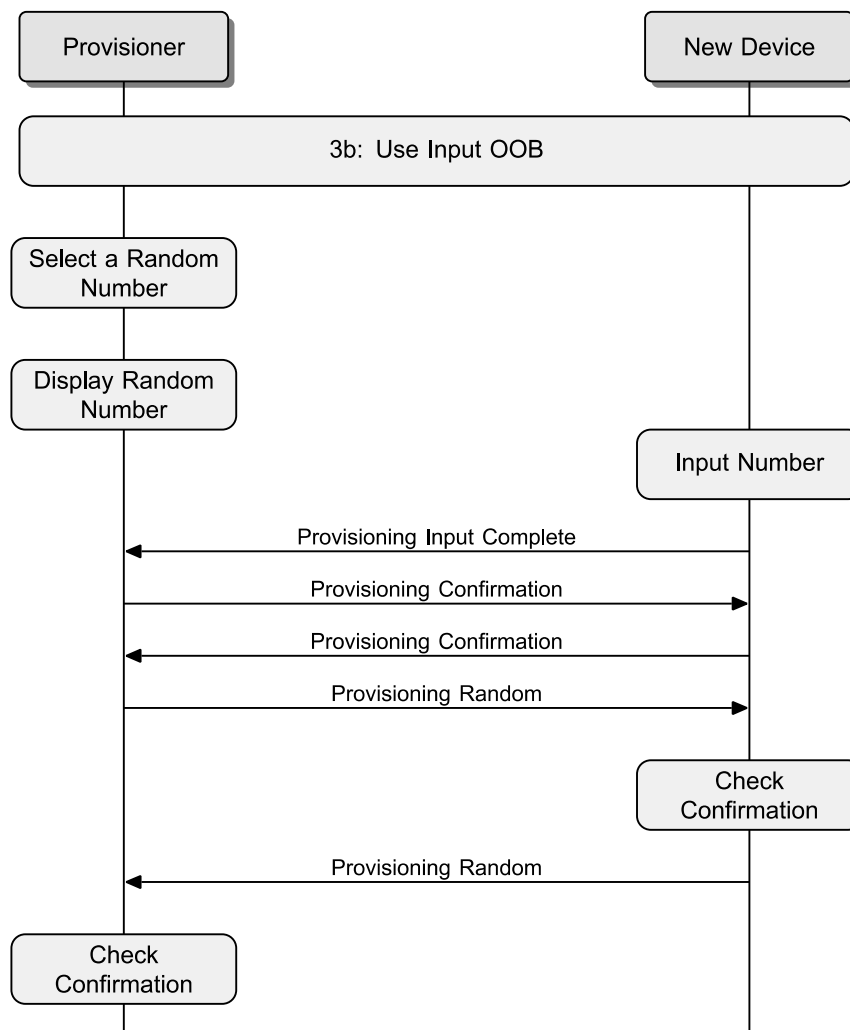


Figure 5.17: Authentication with Input OOB

If static OOB authentication is used, or if no output, input, or static authentication was possible, then the Provisioner shall immediately use the confirmation and random number exchanges as detailed above. If a static OOB value is available, then this value shall be included as part of the confirmation value. If no static OOB value is available, then this value shall have a value of zero.

The message sequence for authentication with Static OOB or No OOB is illustrated by [Figure 5.18](#) below.

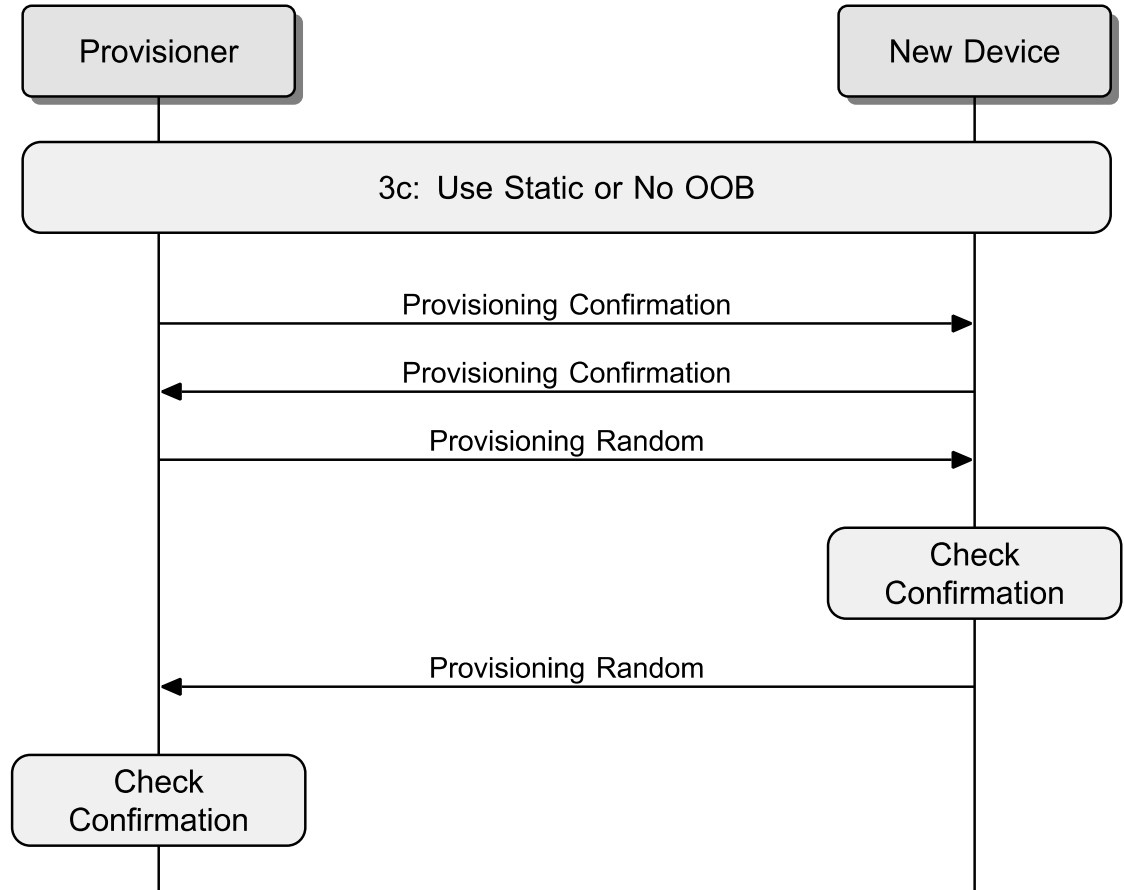


Figure 5.18: Authentication with static OOB or no OOB

5.4.2.5 Distribution of provisioning data

Once the device has been authenticated, the Provisioner and device shall use the calculated Diffie-Hellman shared secret ECDHSecret and generate a session key from that shared secret. That session key shall then be used to encrypt and authenticate the provisioning data. The Provisioner then shall send the Provisioning Data PDU containing the encrypted and authenticated provisioning data to the device.

The provisioning data format is described in [Table 5.39](#).

Field	Size (octets)	Notes
Network Key	16	NetKey
Key Index	2	Index of the NetKey

Flags	1	Flags bitmask
IV Index	4	Current value of the IV Index
Unicast Address	2	Unicast address of the primary element

Table 5.39: Provisioning data format

The Network Key shall contain the NetKey.

The Key Index field shall identify the global NetKey Index of the Network Key and shall be encoded as defined in Section 4.3.1.1.

The Flags field is defined in Table 3.41 as:

Bits	Definition
0	Key Refresh Flag 0: Key Refresh Phase 0 1: Key Refresh Phase 2
1	IV Update Flag 0: Normal operation 1: IV Update active
2–7	Reserved for Future Use

Table 5.40: Flags field definition

The IV Index field shall contain the current value of the IV Index.

The Unicast Address shall contain the Unicast Address of the primary element of the node being added to the network.

The Session key shall be derived using the formula:

$$\text{ProvisioningSalt} = \text{s1}(\text{ConfirmationSalt} \parallel \text{RandomProvisioner} \parallel \text{RandomDevice})$$

$$\text{SessionKey} = \text{k1}(\text{ECDHSecret}, \text{ProvisioningSalt}, \text{"prsk"})$$

The nonce shall be the 13 least significant octets of:

$$\text{SessionNonce} = \text{k1}(\text{ECDHSecret}, \text{ProvisioningSalt}, \text{"prsn"})$$

The provisioning data shall be encrypted and authenticated using:

$$\text{Provisioning Data} = \text{Network Key} \parallel \text{Key Index} \parallel \text{Flags} \parallel \text{IV Index} \parallel \text{Unicast Address}$$

$$\text{Encrypted Provisioning Data, Provisioning Data MIC} = \text{AES-CCM}(\text{SessionKey}, \text{SessionNonce}, \text{Provisioning Data})$$

The size of the Provisioning Data MIC is 8 octets.

The Encrypted Provisioning Data and Provisioning Data MIC shall be used as fields in the Provisioning Data PDU. The Provisioner shall send the Provisioning Data PDU to the device.

The device shall then compute the device key as defined in Section 3.8.6.1.

The message sequence for distribution of provisioning data is illustrated by Figure 5.19 below.

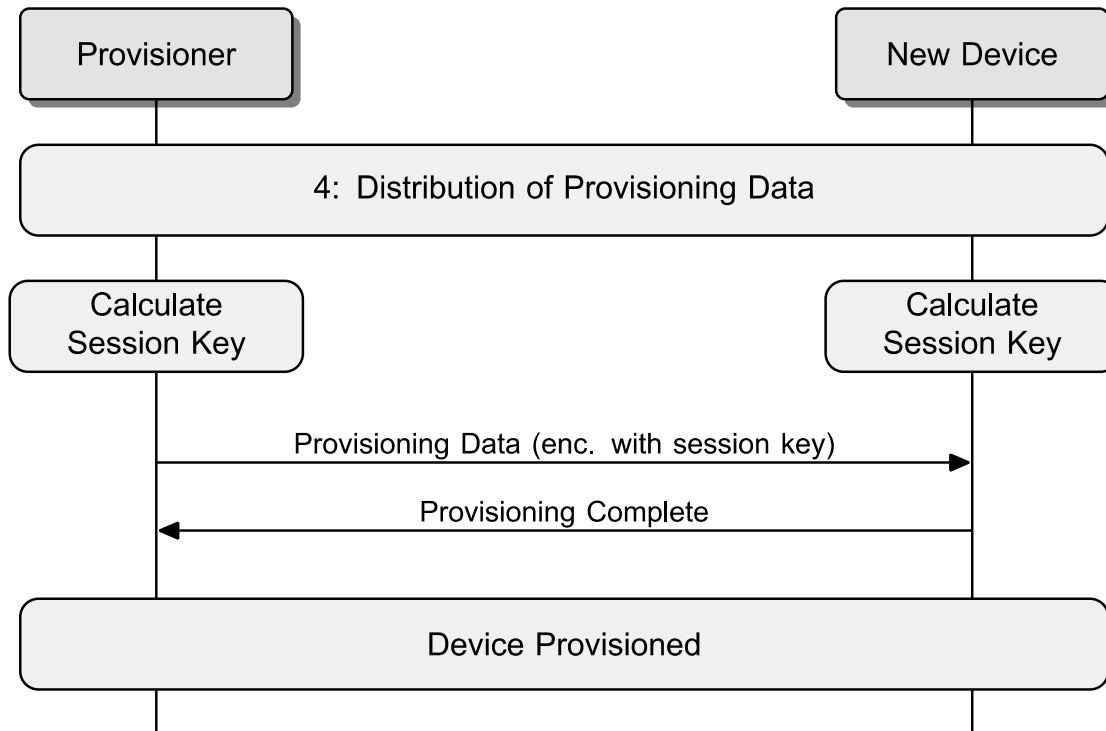


Figure 5.19: Distribution of provisioning data

The Provisioner and device calculate the device key using the k1 key derivation function based on the established Diffie-Hellman shared secret ECDHSecret.

Upon receiving the Provisioning Data PDU from the Provisioner, the device shall decrypt and authenticate the provisioning data. Upon successful authentication of the provisioning data, the device shall set the network key (identified by the Key Index), set the IV index, set the IV Update procedure state based on the IV Update Flag, set the Key Refresh Phase based on the Key Refresh Flag, and assign unicast addresses to all device elements starting from primary element using consecutive range of addresses starting from provided unicast address value. Upon successful completion of the address assigning procedure, the device shall respond with a Provisioning Complete PDU to confirm that it has been provisioned. If the address assigning cannot be successfully completed, the device shall assume that provisioning failed and respond with Provisioning Failed PDU with the Error Code parameter set to Cannot Assign Addresses.

Note: After the processing the Provisioning Data PDU from the Provisioner, the 96 hour time limits for changing the IV Update procedure state, as defined in the IV Update procedure, do not apply.

Upon receiving the Provisioning Complete PDU from the device, the Provisioner shall assume that provisioning process is completed successfully and the device is using a consecutive range of address starting from the value of the unicast address. The length of the address range is reported to the Provisioner in Provisioning Capabilities PDU (see Section 5.4.1.2). As a final step in procedure, the Provisioner shall disconnect the provisioning bearer. The device is now a node in the mesh network.

The Provisioner must not reuse unicast addresses that have been allocated to a device and sent in a Provisioning Data PDU until the Provisioner receives an Unprovisioned Device beacon or Service Data for the Mesh Provisioning Service from that same device, identified using the Device UUID of the device.

5.4.3 Provisioning security

All devices and Provisioners shall support the FIPS P-256 Elliptic Curve Algorithm.

Provisioning may be secure or insecure. Secure Provisioning requires the following method:

- FIPS P-256 Elliptic Curve Algorithm, a Public Key Type that is not transferred in band (i.e., "OOB Public Key is used" is selected), and a Static OOB of any size.
- FIPS P-256 Elliptic Curve Algorithm; OOB Action of Input Numeric, Input Alphanumeric, Output Numeric, or Output Alphanumeric; and OOB Size of at least 6 octets.

Otherwise, provisioning is Insecure Provisioning.

It is recommended that devices and Provisioners support Secure Provisioning. A Provisioner may have a policy of only provisioning devices using Secure Provisioning. Devices not supporting Secure Provisioning will not be able to be provisioned by a Provisioner that is only using Secure Provisioning.

5.4.3.1 FIPS P-256 Elliptic Curve definition

The FIPS-P256 curve is defined in FIPS 186-3 [12].

Elliptic curves are specified by p , a , and b in the form of:

$$E: y^2 = x^3 + ax + b \pmod{p}$$

For each value of b , a unique curve can be developed. In NIST P-256:

$$a = \text{mod}(-3, p)$$

b is defined and its method of generation can be verified by using SHA-1 (with a given seed s and using $b^2c = -27 \pmod{p}$)

The following parameters are given:

- The prime modulus p , order r , base point x -coordinate G_x , base point y -coordinate G_y .
- The integers p and r are given in decimal form; bit strings and field elements are given in hex.

$p = 115792089210356248762697446949407573530086143415290314195533631308867097853951$

$r = 11579208921035624876269744694940757352999695522413576034242259061068512044369$



b = 5ac635d8 aa3a93e7 b3ebbd55 769886bc 651d06b0 cc53b0f6 3bce3c3e 27d2604b

Gx = 6b17d1f2 e12c4247 f8bce6e5 63a440f2 77037d81 2deb33a0 f4a13945 d898c296

Gy = 4fe342e2 fe1a7f9b 8ee7eb4a 7c0f9e16 2bce3357 6b315ece cbb64068 37bf51f5

The function P-256 is defined as follows. Given an integer u , $0 < u < r$, and a point V on the curve E , the value P-256(u , V) is computed as the x-coordinate of the u^{th} multiple uV of the point V .

The private keys shall be between 1 and $r/2$, where r is the Order of the Abelian Group on the elliptic curve (i.e., between 1 and $2^{256}/2$).

A valid public key $Q = (X_Q, Y_Q)$ is one where X_Q and Y_Q are both in the range 0 to $p - 1$ and satisfy the equation $(Y_Q)^2 = (X_Q)^3 + aX_Q + b \pmod{p}$ in the relevant curve's finite field.

Note: For additional information about public key validation, see NIST Special Publication 800-56A, Revision 3 [13].

5.4.3.2 Provisioning key derivation

Figure 5.20 and Figure 5.21 illustrate the derivation of the provisioning keys.

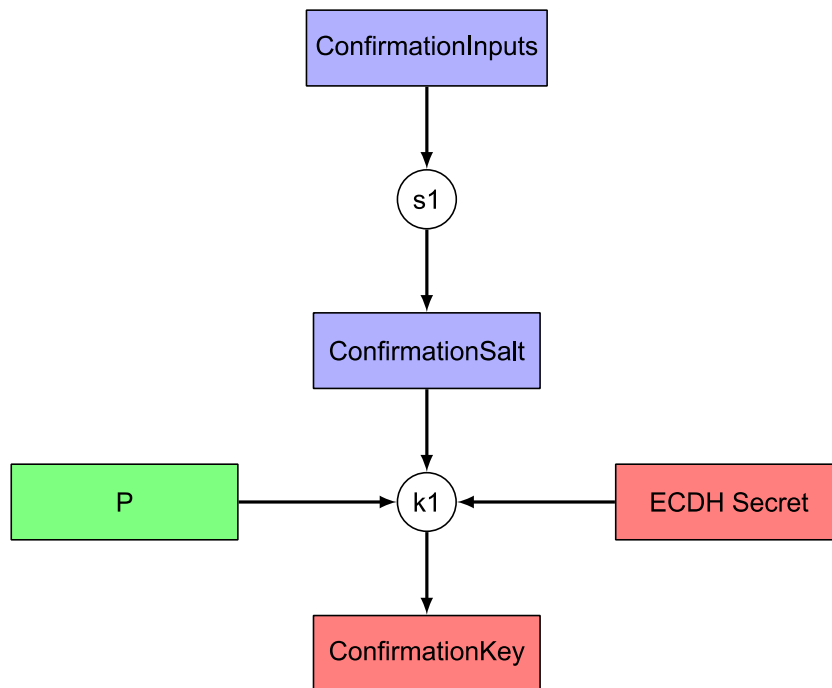


Figure 5.20: ConfirmationKey derivation

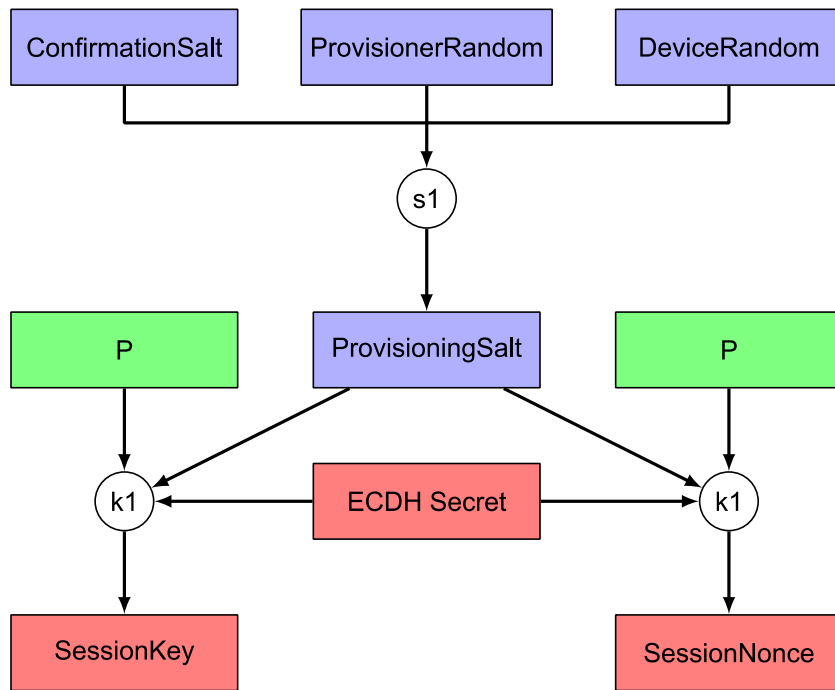


Figure 5.21: SessionKey and SessionNonce Key derivation

5.4.4 Provisioning errors

When the provisioning protocol fails for any reason, the devices shall permanently delete any stored details. There is no recovery procedure and the whole provisioning procedure must be started from the beginning if the Provisioner chooses to do so.

The provisioning protocol is asymmetric when handling protocol errors. When the Provisioner encounters an error in the provisioning protocol, it shall immediately disconnect the provisioning bearer. Upon an unexpected situation where the provisioning bearer closes, the provisioning protocol has failed.

When the device encounters an error other than a timeout in the provisioning protocol, it shall send the Provisioning Failed PDU with an appropriate Error Code and wait for the closing of the provisioning bearer. At this time, any provisioning protocol PDU received from the Provisioner is considered unexpected.

The Provisioner, upon receiving the Provisioning Failed PDU, shall assume that the provisioning failed and immediately disconnect the provisioning bearer.

The provisioning protocol shall have a minimum timeout of 60 seconds that is reset each time a provisioning protocol PDU is sent or received. The timeout starts when device receives first Provisioning PDU and when the Provisioner sends first Provisioning PDU. If a PDU is not received before the timeout expires, then the protocol has failed. In the case of protocol timeout, the device shall not send a Provisioning Failed PDU.

6 Proxy protocol

The proxy protocol enables nodes to send and receive Network PDUs, mesh beacons, proxy configuration messages and Provisioning PDUs over a connection-oriented bearer.

For example, a node could support GATT but not be able to advertise the Mesh Message AD Type. This node will establish a GATT connection with another node that supports the GATT bearer and the advertising bearer, using the Proxy protocol to forward messages between these bearers.

6.1 Endianness

Unless stated otherwise, all multiple-octet numeric values in this protocol shall be “big endian”, as described in Section 3.1.1.1.

6.2 Proxy roles

The proxy protocol defines two roles: the Proxy Server and the Proxy Client.

The Proxy Server is a node that supports a mesh bearer using the Proxy protocol and at least one other mesh bearer. For example, the Proxy Server can forward mesh messages between the advertising bearer and the GATT bearer.

The Proxy Client supports a mesh bearer using the Proxy protocol. For example, the Proxy Client can use the GATT bearer to send mesh messages to a node that supports the advertising bearer.

6.3 Proxy PDU

A Proxy Client and a Proxy Server exchange Proxy PDUs. Proxy PDUs can contain Network PDUs, mesh beacons, proxy configuration messages or Provisioning PDUs. A single Proxy PDU can contain a full message or a segment of a message. The size of the Proxy PDU is determined by the user of the Proxy protocol. For example, the GATT bearer defines the size of the Proxy PDU based on the ATT_MTU.

6.3.1 PDU format

The format of a Proxy PDU is illustrated in Figure 6.1 and defined in Table 6.1.

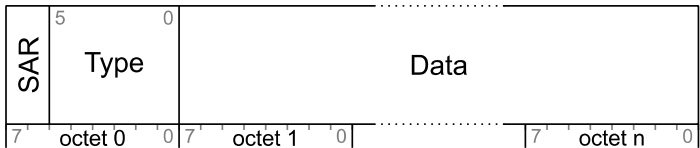


Figure 6.1: Proxy PDU format

Field Name	Size (bits)	Notes
SAR	2	Message segmentation and reassembly information
MessageType	6	Type of message contained in the PDU



Field Name	Size (bits)	Notes
Data	Variable	Full message or message segment

Table 6.1: Proxy PDU format

The SAR field shown in [Table 6.2](#) identifies the message segmentation and defines the contents of the Data field:

Value	Description
0b00	Data field contains a complete message
0b01	Data field contains the first segment of a message
0b10	Data field contains a continuation segment of a message
0b11	Data field contains the last segment of a message

Table 6.2: SAR field values

The MessageType field shown in [Table 6.3](#) identifies the type of message contained in the Proxy PDU:

Type	Name	Description
0x00	Network PDU	The message is a Network PDU as defined in Section 3.4.4 .
0x01	Mesh Beacon	The message is a mesh beacon as defined in Section 3.9 .
0x02	Proxy Configuration	The message is a proxy configuration message as defined in Section 6.5 .
0x03	Provisioning PDU	The message is a Provisioning PDU as defined in Section 5.4.1 .
0x04–0x3F	RFU	Reserved for Future Use.

Table 6.3: MessageType values

The Data field contains a message defined by the MessageType field segmented as defined by the SAR field.

6.3.2 Segmentation

Messages sent using the Proxy protocol may be larger than an individual Proxy PDU. To enable such messages to be transmitted, segmentation and reassembly is used.

When sending a message that is less than or equal to the maximum size of a Proxy PDU, the SAR field shall be set to 0b00 and the Data field shall contain the complete message.

When sending a message that is greater than the maximum size of a Proxy PDU, the message is divided into segments that will fill each Proxy PDU except for the last Proxy PDU that may or may not be filled. These segments shall be sent in order and the SAR field of the first segment shall be set to 0b01, the SAR field of the last segment shall be set to 0b11, and all other segments shall have the SAR field set to 0b10.

6.4 Proxy filtering

In order to reduce the number of Network PDUs exchanged between a Proxy Client and a Proxy Server, a proxy filter can be used.

The output filter of the network interface (see Section 3.4.5) instantiated by the Proxy Server can be configured by the Proxy Client. This allows the Proxy Client to explicitly request to receive only mesh messages with certain destination addresses. For example, a Proxy Client that is subscribed to a group address may want to only receive packets addressed to the unicast address of one of its elements and to that group address. Thus, the Proxy Client has full control over the packets it receives using the Proxy protocol.

6.4.1 Filter types

A proxy filter can be either a white list filter or a black list filter.

A white list filter has an associated white list, which is a list of destination addresses that are of interest for the Proxy Client. The white list filter blocks all destination addresses except those that have been added to the white list.

A black list filter has an associated black list, which is a list of destination addresses that the Proxy Client does not want to receive. The black list filter accepts all destination addresses except those that have been added to the black list.

The white list filter with an empty list is the default filter type. The Proxy Client can change the filter type as well as configure the addresses in the proxy filter.

6.5 Proxy configuration messages

In addition to Network PDUs, mesh beacons and Provisioning PDUs, the Proxy Client and Proxy Server can exchange proxy configuration messages using the Proxy protocol.

Proxy configuration messages are used to configure the proxy filters.

The format of a proxy configuration message is identical to a Network PDU as defined in Table 3.7.

The CTL field shall be set to 1.

The TTL field shall be set to 0.

The DST field shall be set to the unassigned address.

The TransportPDU field shall be formatted as shown in Table 6.4 and shall be secured using the master security credentials as defined in Section 3.8.6.3.1, with the proxy nonce as defined in Section 3.8.5.4.



Field Name	Size (octets)	Notes
Opcode	1	Message opcode
Parameters	variable	Message parameters

Table 6.4: Proxy TransportPDU field format

The Opcode field values are defined in [Table 6.5](#):

Value	Opcode	Notes
0x00	Set Filter Type	Sent by a Proxy Client to set the proxy filter type.
0x01	Add Addresses To Filter	Sent by a Proxy Client to add addresses to the proxy filter list.
0x02	Remove Addresses From Filter	Sent by a Proxy Client to remove addresses from the proxy filter list.
0x03	Filter Status	Acknowledgment by a Proxy Server to a Proxy Client to report the status of the proxy filter list.
0x04–0xFF	RFU	Reserved for Future Use

Table 6.5: Proxy Configuration message opcodes

The Parameters field is specific to each opcode and is defined in the following subsections.

6.5.1 Set Filter Type

The Set Filter Type message can be sent by a Proxy Client to change the proxy filter type and clear the proxy filter list.

The parameters of this message are defined in [Table 6.6](#):

Field	Size (octets)	Notes
FilterType	1	The proxy filter type.

Table 6.6: Set Filter Type Message Format

The values for the FilterType field are defined in [Table 6.7](#):

Value	Notes
0x00	White list filter
0x01	Black list filter
0x02–0xFF	Prohibited

Table 6.7: FilterType Values



6.5.2 Add Addresses to Filter

The Add Addresses to Filter message is sent by a Proxy Client to add destination addresses to the proxy filter list.

The parameters of this message are defined in [Table 6.8](#):

Field	Size (octets)	Notes
AddressArray	2 * N	List of addresses where N is the number of addresses in this message.

Table 6.8: Add Addresses to Filter message format

The AddressArray field contains a sequence of addresses to be added to the proxy filter list. It may contain any combination of unicast addresses, virtual addresses, and group addresses.

Note: Each address in the AddressArray is a 16-bit value and therefore the 16-bit virtual address and not the Label UUID is used.

6.5.3 Remove Addresses from Filter

The Remove Addresses from Filter message is sent by a Proxy Client to remove destination addresses from the proxy filter list.

The parameters of this message are defined in [Table 6.9](#):

Field	Size (octets)	Notes
AddressArray	2 * N	List of addresses where N is the number of addresses in this message.

Table 6.9: Remove Addresses from Filter message format

The AddressArray field contains a sequence of addresses to be removed from the proxy filter list. It may contain any combination of unicast addresses, virtual addresses, or group addresses.

Note: Each address in the AddressArray is a 16-bit value and therefore the 16-bit virtual address and not the Label UUID is used.

6.5.4 Filter Status

The Filter Status message is sent by a Proxy Server to report the status of the proxy filter.

The parameters of this message are defined in [Table 6.10](#):

Field	Size (octets)	Notes
FilterType	1	White list or black list.
ListSize	2	Number of addresses in the proxy filter list.

Table 6.10: Filter Status message format



The values for the FilterType field are defined in [Table 6.7](#).

The ListSize field contains the number of addresses in the proxy filter list.

6.6 Proxy Server behavior

When a Proxy Client connects to a Proxy Server, an instance of a new bearer is connected to the network layer via a network interface (see [Section 3.4.5](#)).

Upon connection, the Proxy Server shall initialize the proxy filter as a white list filter and the white list shall be empty.

If the proxy filter is a white list filter, upon receiving a valid Mesh message from the Proxy Client, the Proxy Server shall add the unicast address contained in the SRC field of the message to the white list.

If the proxy filter is a black list filter, upon receiving a valid Mesh message from the Proxy Client, the Proxy Server shall remove the unicast address contained in the SRC field of the message from the black list.

Upon connection, the Proxy Server shall send a Secure Network Beacon for each known subnet to the Proxy Client.

Upon successfully processing a Secure Network Beacon with new values for the IV Index field or the Flags field, the Proxy Server shall send this Secure Network Beacon to the Proxy Client.

When the Proxy Server is added to a new subnet, it shall send a Secure Network Beacon for that subnet to the Proxy Client.

Upon receiving a Secure Network Beacon from the Proxy Client, the Proxy Server shall process it as defined in [Section 3.9.3.1](#).

When sending a proxy configuration message, a Proxy Server shall set the SRC field to the unicast address of its primary element and the SEQ field shall use the sequence number of its primary element.

If a Proxy Server receives a Set Filter Type message, it shall set the proxy filter type as requested in the message parameter, and it shall clear the proxy filter list. The Proxy Server shall then respond with a Filter Status message.

If the Proxy Server receives an Add Addresses to Filter message, then it shall add these addresses to the proxy filter list and shall respond with a Filter Status message. If one or more addresses contained in the message are already in the list, the Proxy Server shall not add these addresses. If the Proxy Server runs out of space in the proxy filter list, the Proxy Server shall not add these addresses. If the AddressArray field contains the unassigned address, the Proxy Server shall ignore that address.

If the Proxy Server receives a Remove Addresses from Filter message, it shall remove these addresses from the proxy filter list and shall respond with a Filter Status message. If one or more addresses contained in the message were not in the list, the Proxy Server shall ignore these addresses. If the AddressArray field contains the unassigned address, the Proxy Server shall ignore that address.

Upon receiving a message with an unexpected value of the SAR field, the Proxy Server shall disconnect.

Upon receiving a message with the Message Type field set to a value that is Reserved for Future Use, the Proxy Server shall ignore this message.

The timeout for the SAR transfer is 20 seconds. When the timeout expires, the Proxy Server shall disconnect.

6.7 Proxy Client behavior

The Proxy Client may send proxy configuration messages to configure the proxy filter.

When sending a proxy configuration message, the Proxy Client shall set the SRC field to the unicast address of its primary element and the SEQ field shall use the sequence number of its primary element. The Proxy Client can determine the state of the proxy filter list when it receives a Filter Status message.

Upon receiving a message with an unexpected value of the SAR field, the Proxy Client shall disconnect.

Upon receiving a message with the Message Type field set to a value that is Reserved for Future Use, the Proxy Client shall ignore this message.

The timeout for the SAR transfer is 20 seconds. When the timeout expires, the Proxy Client shall disconnect.

6.8 MSC examples

6.8.1 White list filtering

The MSC shown in [Figure 6.2](#) illustrates the white list filtering performed by the Proxy Server, as configured by the Proxy Client.

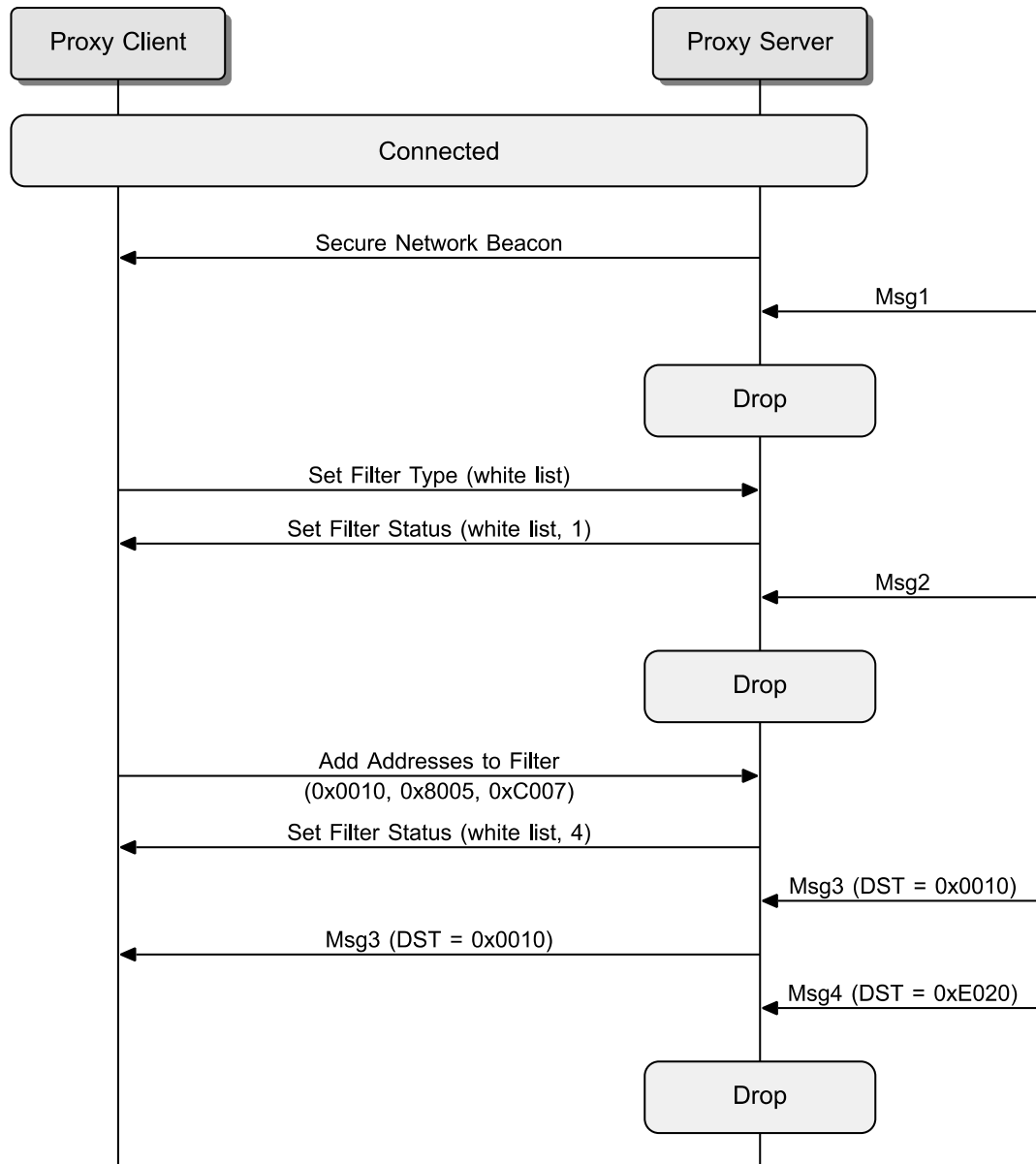


Figure 6.2: White list filtering

6.8.2 Black list filtering

The MSC shown in [Figure 6.3](#) illustrates the black list filtering performed by the Proxy Server, as configured by the Proxy Client.

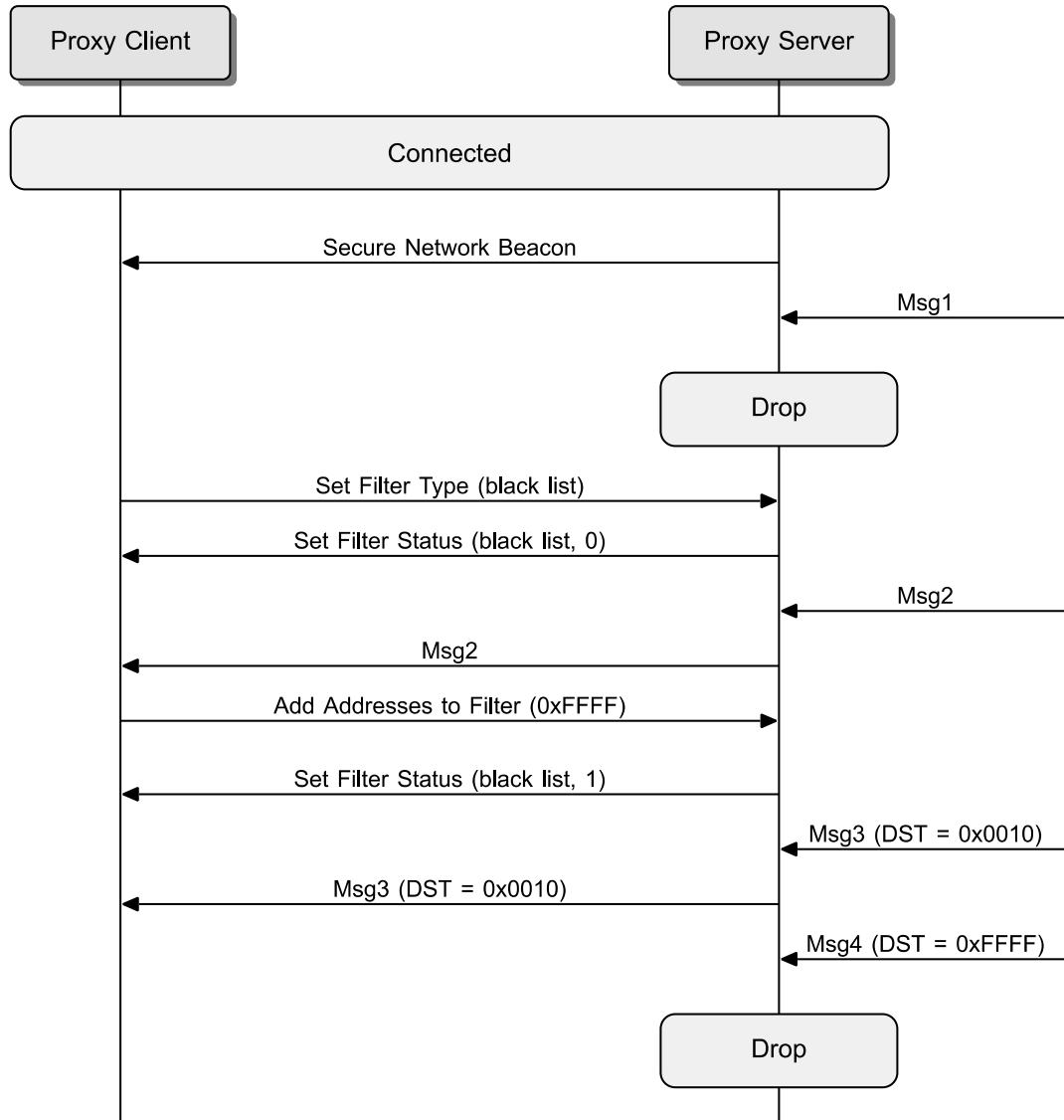


Figure 6.3: Black list filtering

7 Mesh GATT services

This section defines two GATT-based services: The Mesh Provisioning Service and the Mesh Proxy Service.

A device may support the Mesh Provisioning Service or the Mesh Proxy Service or both. If both are supported, only one of these services shall be exposed in the GATT database at a time.

7.1 Mesh Provisioning Service

7.1.1 Introduction

The Mesh Provisioning Service allows a Provisioning Client to provision a Provisioning Server to allow it to participate in the mesh network.

7.1.1.1 Conformance

If a device claims conformance to this service, all capabilities indicated as mandatory for this service shall be supported in the specified manner (process-mandatory). This also applies for all optional and conditional capabilities for which support is indicated.

7.1.1.2 Service dependency

This service has no dependencies on other GATT-based services.

7.1.1.3 Bluetooth specification release compatibility

This service is compatible with any Bluetooth Core Specification that includes the Generic Attribute Profile (GATT) and the Bluetooth Low Energy Controller portions of the Core Specification.

- Bluetooth Core Specification 4.0 or later [1].

7.1.1.4 GATT sub-procedure requirements

Requirements in this section represent a minimum set of requirements for a server. Other GATT sub-procedures may be used if supported by both client and server.

Table 7.1 summarizes *additional* GATT sub-procedures required beyond those required by all GATT servers.



GATT Sub-procedure	Requirements
Write Without Response	M
Notifications	M
Write Characteristic Descriptors	M

Table 7.1: Additional GATT sub-procedure requirements

7.1.1.5 Transport dependencies

The Mesh Provisioning Service operates over the low energy transport only. The specified functionality enables devices to participate in low energy mesh networks, and therefore support for the Bluetooth low energy transport is required.

7.1.1.6 Application error codes

No application error codes are defined by this service.

7.1.2 Service requirements

7.1.2.1 Declaration

The Mesh Provisioning Service shall be instantiated as a «Primary Service».

There shall only be one instance of the Mesh Provisioning Service on an unprovisioned Provisioning Server.

After the Provisioning Server has been provisioned, the Mesh Provisioning Service on that Provisioning Server shall cease to be present in the GATT database for that GATT Client as long as the node remains provisioned.

The Service UUID shall be set to «Mesh Provisioning Service», as defined in [4].

7.1.2.2 Behaviors

The Mesh Provisioning Service may be used by a Provisioning Client to provision a Provisioning Server to participate in a mesh network.

7.1.2.2.1 Advertising

The Provisioning Server is only active and advertising when the device is not provisioned. The Provisioning Server shall be discoverable.

The advertisement shall follow the format as defined in Table 7.2.

AD Type	Total Length	Requirement	Comments
«Flags»	3	M	
«Incomplete List of 16-bit Service UUIDs» or «Complete List of 16-bit Service UUIDs»	4	M	Include «Mesh Provisioning Service»
«Service Data»	22	M	Service Data AD Type for «Mesh Provisioning Service» followed by Service Data for this service

Table 7.2: Advertisement Data for the Mesh Provisioning Service

The format of the Service Data for the «Mesh Provisioning Service» is defined in Table 7.3 and illustrated in Figure 7.1.

Field	Size (octets)	Notes
Device UUID	16	See Section 3.10.3
OOB Information	2	See Table 3.54

Table 7.3: Service Data for Mesh Provisioning Service

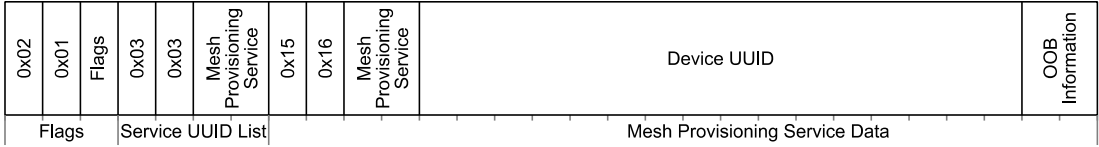


Figure 7.1: PB-GATT Advertising Data

If PB-ADV is supported, an unprovisioned Provisioning Server that supports PB-GATT has to interleave the connectable advertising for PB-GATT with the Unprovisioned Device beacon (see Section 3.9.2).

It is required to include the Service UUID List to allow discovery of the Mesh Provisioning service.

URI, Appearance, TX Power Level, and Local Name AD types can optionally be included in the scan response data. The Provisioning Server should support these data types to allow a Provisioning Client to enhance the user experience while provisioning.

7.1.2.2.2 ATT_MTU

The Provisioning Server should support an ATT_MTU size equal to or larger than 69 octets to accommodate the longest known Provisioning message (see Section 5.3).

7.1.3 Mesh Provisioning Service characteristics

The characteristics shown in Table 7.4 are exposed in the Mesh Provisioning Service. Only one instance of each characteristic is permitted within this service. The characteristic formats and UUIDs are defined in [4].



Where a characteristic can be notified, a Client Characteristic Configuration descriptor shall be included in that characteristic as required by the Core Specification [1].

Characteristic Name	Requirement	Mandatory Properties	Optional Properties	Security Permissions
Mesh Provisioning Data In	M	Write Without Response	None	Writeable with or without authentication or authorization when Unprovisioned
Mesh Provisioning Data Out	M	Notify	None	Notifiable with or without authentication or authorization when Unprovisioned

Table 7.4: Mesh Provisioning Service characteristics

7.1.3.1 Mesh Provisioning Data In characteristic

The Mesh Provisioning Data In characteristic can be written to send a Proxy PDU message (see Section 6.3.1) containing Provisioning PDU (see Section 5.3) to the Provisioning Server.

The Mesh Provisioning Data In characteristic is identified using the UUID «Mesh Provisioning Data In», as defined in [4].

The characteristic value is 66 octets long to accommodate the longest known Proxy PDU containing Provisioning PDU.

7.1.3.1.1 Characteristic behavior

The Mesh Provisioning Data In characteristic is used to transmit Proxy PDU message containing Provisioning PDU from a Provisioning Client to a Provisioning Server.

A Provisioning Server is not required to support bonding.

The Mesh Provisioning Data In characteristic shall support Proxy PDU messages containing Provisioning PDUs and shall not support other Proxy PDU type messages.

7.1.3.2 Mesh Provisioning Data Out characteristic

The Mesh Provisioning Data Out characteristic can be notified to send a Proxy PDU message containing Provisioning PDU from a Provisioning Server to a Provisioning Client.

The Mesh Provisioning Data Out characteristic is identified using the UUID «Mesh Provisioning Data Out», as defined in [4].

The characteristic value is 66 octets long to accommodate the longest known Proxy PDU message containing Provisioning PDU.

7.1.3.2.1 Characteristic behavior

The Mesh Provisioning Data Out characteristic is used to Proxy PDU message containing Provisioning PDU from a Provisioning Server to a Provisioning Client.

A Provisioning Server is not required to support bonding. As a bonding relationship is not established between the Provisioning Client and the Provisioning Server, the Provisioning Client shall enable notifications (write value 0x0001) to the Mesh Provisioning Data Out Client Characteristic Configuration Descriptor after a connection is established and before sending the first message of the Proxy PDU.

The Mesh Provisioning Data Out characteristic shall support Proxy PDU messages containing Provisioning PDUs and shall not support other Proxy PDU type messages.

7.2 Mesh Proxy Service

7.2.1 Introduction

The Mesh Proxy Service is used to enable a server to send and receive Proxy PDUs with a client.

7.2.1.1 Conformance

If a device claims conformance to this service, all capabilities indicated as mandatory for this service shall be supported in the specified manner (process-mandatory). This also applies for all optional and conditional capabilities for which support is indicated.

7.2.1.2 Service dependency

This service has no dependencies on other GATT-based services.

7.2.1.3 Bluetooth specification release compatibility

This service is compatible with any Bluetooth Core Specification that includes the Generic Attribute Profile (GATT) and the Bluetooth Low Energy Controller portions of the Core Specification.

- Bluetooth Core Specification 4.0 or later [1].

7.2.1.4 GATT sub-procedure requirements

Requirements in this section represent a minimum set of requirements for a server. Other GATT sub-procedures may be used if supported by both client and server.

Table 7.5 summarizes *additional* GATT sub-procedures required beyond those required by all GATT servers.

GATT Sub-procedure	Requirements
Write Without Response	M
Notifications	M
Write Characteristic Descriptors	M

Table 7.5: Additional GATT sub-procedure requirements



7.2.1.5 Transport dependencies

The Mesh Proxy Service operates over the Bluetooth low energy transport only. The specified functionality enables devices to participate in low energy mesh networks, and therefore support for the Bluetooth low energy transport is required.

7.2.1.6 Application error codes

No application error codes are defined by this service.

7.2.2 Service requirements

7.2.2.1 Declaration

The Mesh Proxy Service shall be instantiated as a «Primary Service».

A device shall only have one instance of the Mesh Proxy Service.

The Service UUID shall be set to «Mesh Proxy Service», as defined in [4].

7.2.2.2 Behaviors

The Node Identity state for any subnet (see Section 4.2.12) indicates if the Mesh Proxy Service is exposed.

If the Node Identity state for any subnet is 0x00 or 0x01, the Mesh Proxy Service shall be present in the GATT database of a provisioned device and the rules for advertising and the GATT characteristics behavior apply as discussed in the following sections.

If the Node Identity state for any subnet is 0x02 the Mesh Proxy Service shall not be present in the GATT database and the UUID for the "Mesh Proxy Service" shall not be indicated in the advertisements.

7.2.2.2.1 Advertising

The server shall use the GAP General Discoverable mode with connectable undirected advertising events in the format described in Table 7.6 below.

AD Type	Total Length	Requirement	Comments
«Flags»	3	M	
«Incomplete List of 16-bit Service UUIDs» or «Complete List of 16-bit Service UUIDs»	4	M	Include «Mesh Proxy Service»
«Service Data»	21	M	Service Data AD Type for «Mesh Proxy Service» followed by Service Data for this service

Table 7.6: Advertisement Data for the Mesh Proxy Service

The format of Service Data for the «Mesh Proxy Service» is defined in Table 7.7.



Field	Size (octets)	Notes
Identification Type	1	See Table 7.8
Identification Parameters	Variable	Format determined by Identification Type field

Table 7.7: Service Data for Mesh Proxy Service

The Identification Type field values are defined in [Table 7.8](#).

Type Value	Description
0x00	Network ID type
0x01	Node Identity type
0x02–0xFF	Reserved for Future Use

Table 7.8: Identification Type values

A node that supports the Proxy feature and has the Proxy feature enabled shall support advertising with Network ID.

A node that does not support the Proxy feature or has the Proxy feature disabled shall not advertise with Network ID.

A node may advertise with Node Identity regardless of the Proxy feature being supported or enabled.

The Identification Parameters for each Identification Type is defined in the subsections below.

The «Mesh Proxy Service» shall be included in the Incomplete List of 16-bit Service UUIDs or the Complete List of 16-bit Service UUIDs.

7.2.2.2.2 Advertising with Network ID

The format of the Service Data for the «Mesh Proxy Service» when Advertising with the Network ID is defined in [Table 7.9](#) and illustrated in [Figure 7.2](#).

When a server is a member of multiple subnets, it shall interleave the advertising of each subnet.

Field	Size (octets)	Notes
Identification Type	1	0x00 (Network ID type)
Network ID	8	Identifies the network

Table 7.9: Service Data for Mesh Proxy Service with Network ID



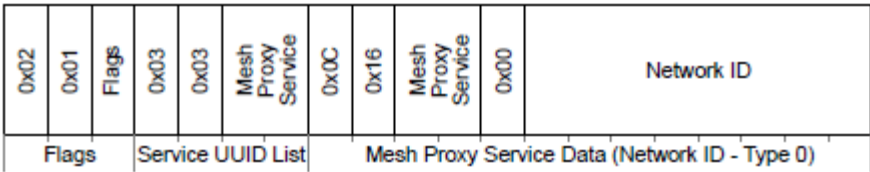


Figure 7.2: Advertising with Network ID (Identification Type 0x00)

The Network ID field shall be set as defined in Section 3.8.6.3.2.

7.2.2.2.3 Advertising with Node Identity

Advertising using the Node Identity is used to identify a node based on the unicast address of the primary element and the network key of a subnet to which the node belongs. This can be useful when large amounts of data need to be delivered to a node via GATT for cases when the node cannot be easily identified or is not advertising. This advertisement may be used to initiate a GATT connection to the selected node.

If PB-GATT is supported and Mesh Proxy Service is exposed, immediately after provisioning is completed using PB-GATT (see Section 5.2.2), the Mesh Proxy Service shall start advertising with Node Identity using the provisioned network.

When the server starts advertising as a result of user interaction, the server shall interleave the advertising of each subnet it is a member of. When the server starts advertising as a result of the Node Identity state being enabled, the server shall only advertise using the subnet that it was enabled on. The duration of advertising in these two cases is limited to 60 seconds.

The format of the Service Data for the «Mesh Proxy Service» when Advertising with Node Identity is defined in Table 7.10 and illustrated in Figure 7.3.

Field	Size (octets)	Notes
Identification Type	1	0x01 (Node Identity type)
Hash	8	Function of the included random number and identity information.
Random	8	64-bit random number

Table 7.10: Service Data for Mesh Proxy Service with Node Identity

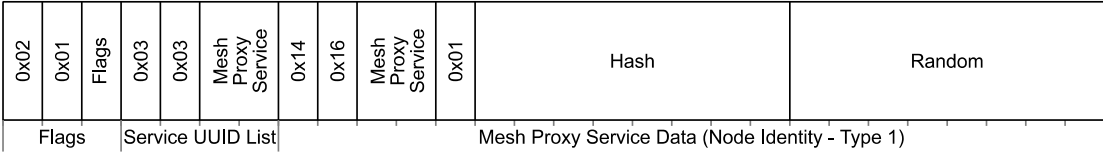


Figure 7.3: Advertising with Node Identity (Identification Type 0x01)



The Hash field is calculated as shown below:

$$\text{Hash} = e(\text{IdentityKey}, \text{Padding} || \text{Random} || \text{Address}) \bmod 2^{64}$$

Where:

Padding – 48 bits of padding, all bits set to 0.

Random – 64 bit random value.

Address – The unicast address of the node.

The Random field is the 64 bit random value used in the Hash field calculation.

The creation of the encrypted node identity is illustrated in [Figure 7.4](#).

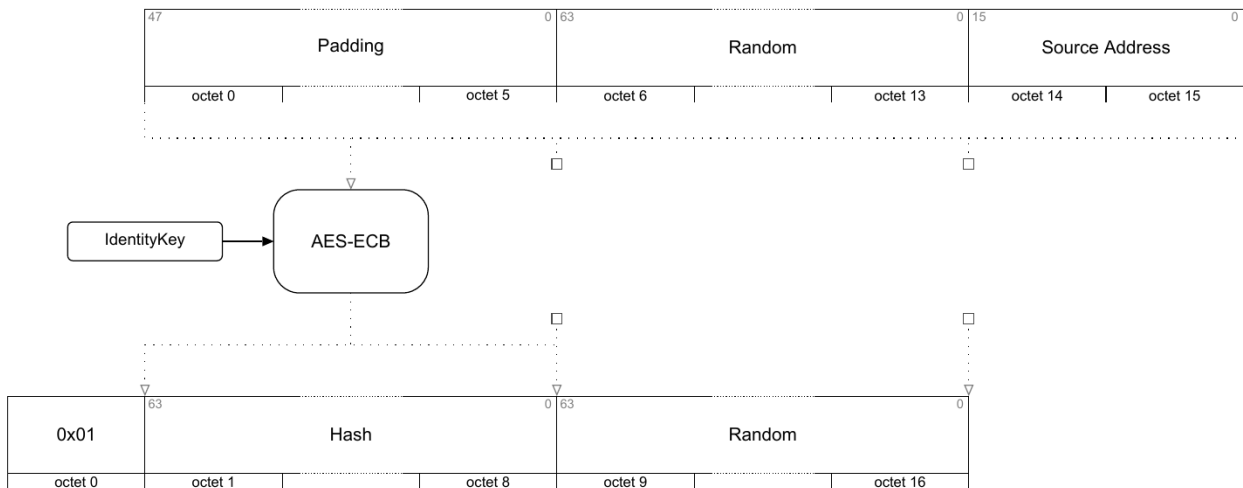


Figure 7.4: Encrypted node identity creation

7.2.2.2.4 ATT_MTU

The server should support an ATT_MTU size equal to or larger than 33 octets to be able to pass the content of a full Proxy PDU (see [Section 6.5](#)).

7.2.3 Mesh Proxy Service characteristics

The characteristics shown in [Table 7.11](#) are exposed by the server. Only one instance of each characteristic is permitted within this service. The characteristic formats and UUIDs are defined in [\[4\]](#).

Where a characteristic can be notified, a Client Characteristic Configuration descriptor shall be included in that characteristic as required by the Core Specification [\[1\]](#).

Characteristic Name	Requirement	Mandatory Properties	Optional Properties	Security Permissions
Mesh Proxy Data In	M	Write Without Response	None	Writeable with or without authentication or authorization when Proxy Service enabled
Mesh Proxy Data Out	M	Notify	None	Notifiable with or without authentication or authorization when Proxy Service enabled

Table 7.11: Mesh Proxy Service characteristics

7.2.3.1 Mesh Proxy Data In characteristic

The Mesh Proxy Data In characteristic is used by the client to send Proxy PDUs (see Section 6.3) to the server.

The Mesh Proxy Data In characteristic is identified using the UUID «Mesh Proxy Data In», as defined in [4]. The characteristic value has the same format as the Proxy PDU.

7.2.3.1.1 Characteristic behavior

When the client sends a Proxy PDU to the server by executing a GATT Write Without Response procedure on this characteristic, the Attribute Value field of the ATT Write Command packet contains the Proxy PDU.

The Mesh Proxy Data In characteristic shall support Proxy PDU messages containing Network PDUs, mesh beacons, and proxy configuration messages and shall not support other Proxy PDU type messages.

7.2.3.2 Mesh Proxy Data Out characteristic

The Mesh Proxy Data Out characteristic is used by the server to send Proxy PDUs to the client.

The Mesh Proxy Data Out characteristic is identified using the UUID «Mesh Proxy Data Out», as defined in [4]. The characteristic value has the same format as the Proxy PDU.

The Mesh Proxy Data Out characteristic shall support Proxy PDU messages containing Network PDUs, mesh beacons, and proxy configuration messages and shall not support other Proxy PDU type messages.

7.2.3.2.1 Characteristic behavior

As a bonding relationship is not required between the client and the server, the client will enable notifications (write value 0x0001) to the Mesh Proxy Data Out Client Characteristic Configuration Descriptor after a connection is established.



The server can send a Proxy PDU to the client by executing a GATT Notification procedure on this characteristic. The Attribute Value field of the ATT Handle Value Notification packet contains the Proxy PDU.

The Mesh Proxy Data Out characteristic shall support Proxy PDU message containing Network PDUs, mesh beacons, and proxy configuration messages and shall not support other Proxy PDU type messages.

8 Sample data

This section provides informative examples of sample data that can be used to verify implementations.

8.1 Security sample data

In this section, all derivations are from the following keys:

```
AppKey           : 3216d1509884b533248541792b877f98
NetKey           : f7a2a44f8e8a8029064f173ddc1e2b00
DevKey (1201)    : 37c612c4a2d337cb7b98355531b3617f
```

8.1.1 s1 SALT generation function

The s1 function is used to generate a 128-bit value, typically known as a “salt” from a sequence of octets. In this case, the sequence of octets is the ASCII string “test”.

```
s1 (test)        : b73cefbdb641ef2ea598c2b6efb62f79c
```

8.1.2 k1 function

The k1 function is used to convert some input key material into some output key material that uses two inputs, known as salt and info.

```
k1 N             : 3216d1509884b533248541792b877f98
k1 SALT          : 2ba14ffa0df84a2831938d57d276cab4
k1 P             : 5a09d60797eeb4478aada59db3352a0d
k1 T             : c764bea25cf9738b08956ea3c712d5af
k1               : f6ed15a8934afbe7d83e8dcb57fcf5d7
```

8.1.3 k2 function (master)

The k2 function is used to convert the master security credentials, NetKey as N, and generate the master security material, NID, EncryptionKey, and PrivacyKey.

```
k2 N             : f7a2a44f8e8a8029064f173ddc1e2b00
k2 P             : 00
k2 s1 (smk2)     : 4f90480c1871bfbffd16971f4d8d10b1
k2 T             : 2ea6467aa3378c4c545eda62935b9b86
k2 T0            :
k2 T1            : 82bea685dc2f1deec255ac643741f5ff
k2 T2            : 9f589181a0f50de73c8070c7a6d27f46
k2 T3            : 4c715bd4a64b938f99b453351653124f
NID              : 7f
EncryptionKey    : 9f589181a0f50de73c8070c7a6d27f46
PrivacyKey       : 4c715bd4a64b938f99b453351653124f
```

8.1.4 k2 function (friendship)

The k2 function is also used to convert the friendship security credentials, NetKey as N, LPNAddress, FriendAddress, LPNCounter, and FriendCounter, and generate the friendship security material NID, EncryptionKey, and PrivacyKey.

```

LPNAddress      : 0203
FriendAddress   : 0405
LPNCounter     : 0607
FriendCounter   : 0809
k2 N            : f7a2a44f8e8a8029064f173ddc1e2b00
k2 P            : 010203040506070809
k2 s1 (smk2)    : 4f90480c1871bfbffd16971f4d8d10b1
k2 T            : 2ea6467aa3378c4c545eda62935b9b86
k2 T0           :
k2 T1           : 3a6b950f56718c1eab2c600a92d4e9f3
k2 T2           : 11efec0642774992510fb5929646df49
k2 T3           : d4d7cc0dfa772d836a8df9df5510d7a7
NID             : 73
EncryptionKey   : 11efec0642774992510fb5929646df49
PrivacyKey      : d4d7cc0dfa772d836a8df9df5510d7a7

```

8.1.5 k3 function

The k3 function is used to generate a 64-bit Network ID used to identify the mesh network in public messages such as a Secure Network beacon.

```

k3 N            : f7a2a44f8e8a8029064f173ddc1e2b00
k3 SALT         : 0036443503f195cc8a716e136291c302
k3 T            : 6da9698c95f500e4edce3bb47f92754f
k3 CMAC("id64" || 0x01) : 3527c5985f0c05ccff046958233db014
Network ID      : ff046958233db014

```

8.1.6 k4 function

The k4 function is used to generate an AID from an application key.

```

k4 N            : 3216d1509884b533248541792b877f98
k4 SALT         : 0e9ac1b7cefa66874c97ee54ac5f49be
k4 T            : 62e5d9240cdb3bb0b2743207ea2d6276
k4 CMAC("id6" || 0x01)  : 1431ea1afeb05224ab892a0217ccab38
AID             : 38

```

8.2 Mesh key derivation sample data

In this section, all derivations are from the following keys. These are the same keys used in the mesh message sample data.

```
AppKey           : 63964771734fbd76e3b40519d1d94a48
NetKey           : 7dd7364cd842ad18c17c2b820c84c3d6
DevKey (1201)    : 9d6dd0e96eb25dc19a40ed9914f8f03f
```

8.2.1 Application key AID

The application keys AID is calculated using the k4 function.

```
k4 N             : 63964771734fbd76e3b40519d1d94a48
k4 SALT          : 0e9ac1b7cefa66874c97ee54ac5f49be
k4 T             : 921cb4f908cc5932e1d7b059fc163ce6
k4 CMAC("id6"||0x01) : 5f79cf09bbdab560e7f1ee404fd341a6
AID              : 26
```

8.2.2 Encryption and privacy keys (Master)

The NID, EncryptionKey, and PrivacyKey for a normal mesh message sent using the master security credentials.

```
k2 N             : 7dd7364cd842ad18c17c2b820c84c3d6
k2 P             : 00
k2 s1 (smk2)     : 4f90480c1871bfbffd16971f4d8d10b1
k2 T             : 39885e0463bafd54ca6e495b1001515a
k2 T0            :
k2 T1            : 88dad4892e81fecbe061ebd3fb093268
k2 T2            : 0953fa93e7caac9638f58820220a398e
k2 T3            : 8b84eedec100067d670971dd2aa700cf
NID              : 68
EncryptionKey     : 0953fa93e7caac9638f58820220a398e
PrivacyKey        : 8b84eedec100067d670971dd2aa700cf
```

8.2.3 Encryption and privacy keys (Friendship)

The NID, EncryptionKey, and PrivacyKey for a mesh message between a Friend node and a Low Power node sent using the friendship security credentials.

```
LPNAddress       : 1201
FriendAddress     : 2345
LPNCounter       : 0000
FriendCounter     : 072f
k2 N             : 7dd7364cd842ad18c17c2b820c84c3d6
k2 P             : 01120123450000072f
k2 s1 (smk2)     : 4f90480c1871bfbffd16971f4d8d10b1
k2 T             : 39885e0463bafd54ca6e495b1001515a
k2 T0            :
```

```

k2 T1      : d91a3b3c63b5c50a98c838e52a4bc0de
k2 T2      : be635105434859f484fc798e043ce40e
k2 T3      : 5d396d4b54d3cbafe943e051fe9a4eb8
NID        : 5e
EncryptionKey : be635105434859f484fc798e043ce40e
PrivacyKey  : 5d396d4b54d3cbafe943e051fe9a4eb8

```

8.2.4 Network ID

The Network ID used to identify this NetKey, for example, in a Secure Network beacon.

```

k3 N      : 7dd7364cd842ad18c17c2b820c84c3d6
k3 SALT   : 0036443503f195cc8a716e136291c302
k3 T      : 36b82fd0fc400e797977bd12d08a4782
k3 CMAC("id64" || 0x01) : ca296bcee3ccc2d33ecaff672f673370
Network ID : 3ecaff672f673370

```

8.2.5 IdentityKey

The Identify key used to help identify the device in the Mesh Proxy Service's Service Data using Node Identity.

```

k1 N      : 7dd7364cd842ad18c17c2b820c84c3d6
k1 SALT   : f8795a1aabf182e4f163d86e245e19f4
k1 P      : 696431323801
k1 T      : 55efb6c898c2a38bc9bd0a6097bfff966
IdentityKey : 84396c435ac48560b5965385253e210c

```

8.2.6 BeaconKey

The Beacon key is used to help secure the Secure Network beacon.

```

k1 N      : 7dd7364cd842ad18c17c2b820c84c3d6
k1 SALT   : 2c24619ab793c1233f6e226738393dec
k1 P      : 696431323801
k1 T      : 829816cd429fde7d238b56d8bf771efb
BeaconKey : 5423d967da639a99cb02231a83f7d254

```

8.3 Mesh message sample data

In this section, all messages are secured using the following keys:

```

AppKey      : 63964771734fbd76e3b40519d1d94a48
NetKey      : 7dd7364cd842ad18c17c2b820c84c3d6
DevKey (1201) : 9d6dd0e96eb25dc19a40ed9914f8f03f

```

The messages below show a typical set of transactions used by a Low Power node that are intended to show multiple examples of mesh messages.

8.3.1 Message #1

This shows an example of a new node that supports the Low Power feature attempting to find a Friend node. It does this by sending a Friend Request with its requirements to the all-friends address using a TTL of zero.

Transport Control Message

```

Opcode           : 03 (Friend Request)
Criteria         : 4b
ReceiveDelay     : 50
PollTimeout      : 057e40
PreviousAddress  : 0000
NumElements      : 01
LPNCounter       : 0000

```

UpperTransportControlPDU

```

TTL              : 00
SEQ              : 000001
SRC              : 1201
DST              : fffd
UpperTransportPDU : 4b50057e400000010000

```

LowerTransportUnsegmentedControlPDU

```

CTL              : 01
TTL              : 00
SEQ              : 000001
SRC              : 1201
DST              : fffd
SEG              : 00
Opcode           : 03
Header           : 03
UpperTransportPDU : 4b50057e400000010000
LowerTransportPDU : 034b50057e400000010000

```

NetworkPDU

```

IVindex          : 12345678
NetKey            : 7dd7364cd842ad18c17c2b820c84c3d6
CTL              : 01
TTL              : 00
SEQ              : 000001
SRC              : 1201
DST              : fffd
LowerTransportPDU : 034b50057e400000010000
NID              : 68

```



```

EncryptionKey      : 0953fa93e7caac9638f58820220a398e
PrivacyKey         : 8b84eedec100067d670971dd2aa700cf
Network Nonce      : 00800000011201000012345678
IVI NID            : 68
CTL TTL            : 80
SEQ                : 000001
SRC                : 1201
DST                : fffd
TransportPDU       : 034b50057e400000010000
NetMIC Size        : 64 bits
EncDST || EncTransportPDU : b5e5bfdacba6cb7fb6bff871f
NetMIC             : 035444ce83a670df

```

Obfuscation

```

Privacy Plaintext  : 000000000012345678b5e5bfdacba6c
PECB              : 6ca487507564
CTL || TTL || SEQ || SRC : 800000011201

NetworkPDU        : 68eca487516765b5e5bfdacba6cb7fb6bff871f035444ce83a670df

```

8.3.2 Message #2

A node that supports the Friend feature responds to the Friend Request with a Friend Offer.

Transport Control Message

```

Opcode           : 04 (Friend Offer)
ReceiveWindow    : 32
QueueSize        : 03
SubListSize      : 08
RSSI             : ba (-70)
FriendCounter     : 072f

```

UpperTransportControlPDU

```

TTL              : 00
SEQ              : 014820
SRC              : 2345
DST              : 1201
UpperTransportPDU : 320308ba072f

```

LowerTransportUnsegmentedControlPDU

```

CTL              : 01
TTL              : 00
SEQ              : 014820
SRC              : 2345
DST              : 1201

```



```

SEG                : 00
Opcode             : 04
Header             : 04
UpperTransportPDU  : 320308ba072f
LowerTransportPDU  : 04320308ba072f

NetworkPDU

IVindex            : 12345678
NetKey             : 7dd7364cd842ad18c17c2b820c84c3d6
CTL               : 01
TTL               : 00
SEQ               : 014820
SRC               : 2345
DST               : 1201
LowerTransportPDU : 04320308ba072f
NID               : 68
EncryptionKey      : 0953fa93e7caac9638f58820220a398e
PrivacyKey         : 8b84eedec100067d670971dd2aa700cf
Network Nonce      : 00800148202345000012345678
IVI NID           : 68
CTL TTL           : 80
SEQ               : 014820
SRC               : 2345
DST               : 1201
TransportPDU       : 04320308ba072f
NetMIC Size        : 64 bits
EncDST || EncTransportPDU : 79d7dbc0c9b4d43eeb
NetMIC             : ec129d20a620d01e

Obfuscation

Privacy Plaintext  : 00000000001234567879d7dbc0c9b4d4
PECB              : 54c96e094e3c
CTL || TTL || SEQ || SRC : 800148202345

NetworkPDU         : 68d4c826296d7979d7dbc0c9b4d43eebec129d20a620d01e

```

8.3.3 Message #3

Another node supporting the Friend feature responds with another Friend Offer. This Friend Offer has a smaller queue size and a significantly worse RSSI figure than the other Friend Offer message.

Transport Control Message

```

Opcode            : 04 (Friend Offer)
ReceiveWindow     : fa
QueueSize         : 02
SubListSize       : 05

```



RSSI : a6 (-90)
 FriendCounter : 000a

UpperTransportControlPDU

TTL : 00
 SEQ : 2b3832
 SRC : 2fe3
 DST : 1201
 UpperTransportPDU : fa0205a6000a

LowerTransportUnsegmentedControlPDU

CTL : 01
 TTL : 00
 SEQ : 2b3832
 SRC : 2fe3
 DST : 1201
 SEG : 00
 Opcode : 04
 Header : 04
 UpperTransportPDU : fa0205a6000a
 LowerTransportPDU : 04fa0205a6000a

NetworkPDU

IVindex : 12345678
 NetKey : 7dd7364cd842ad18c17c2b820c84c3d6
 CTL : 01
 TTL : 00
 SEQ : 2b3832
 SRC : 2fe3
 DST : 1201
 LowerTransportPDU : 04fa0205a6000a
 NID : 68
 EncryptionKey : 0953fa93e7caac9638f58820220a398e
 PrivacyKey : 8b84eedec100067d670971dd2aa700cf
 Network Nonce : 00802b38322fe3000012345678
 IVI NID : 68
 CTL TTL : 80
 SEQ : 2b3832
 SRC : 2fe3
 DST : 1201
 TransportPDU : 04fa0205a6000a
 NetMIC Size : 64 bits
 EncDST || EncTransportPDU : 53273086b8c5ee00bd
 NetMIC : d9cfcc62a2ddf572



Obfuscation

Privacy Plaintext : 00000000001234567853273086b8c5ee
 PECB : 5a2d13fb4211
 CTL|TTL|SEQ|SRC : 802b38322fe3
 NetworkPDU : 68da062bc96df253273086b8c5ee00bdd9cfcc62a2ddf572

8.3.4 Message #4

The node sends a Friend Poll to confirm the friendship with one of the Friend nodes.

Transport Control Message

Opcode : 01 (Friend Poll)
 FSN : 0

UpperTransportControlPDU

TTL : 00
 SEQ : 000002
 SRC : 1201
 DST : 2345
 UpperTransportPDU : 00

LowerTransportUnsegmentedControlPDU

CTL : 01
 TTL : 00
 SEQ : 000002
 SRC : 1201
 DST : 2345
 SEG : 00
 Opcode : 01
 Header : 01
 UpperTransportPDU : 00
 LowerTransportPDU : 0100

NetworkPDU

IVindex : 12345678
 NetKey : 7dd7364cd842ad18c17c2b820c84c3d6
 LPNAddress : 1201
 FriendAddress : 2345
 LPNCounter : 0000
 FriendCounter : 072f
 CTL : 01
 TTL : 00
 SEQ : 000002



```

SRC                : 1201
DST                : 2345
LowerTransportPDU  : 0100
NID                : 5e
EncryptionKey      : be635105434859f484fc798e043ce40e
PrivacyKey         : 5d396d4b54d3cbafe943e051fe9a4eb8
Network Nonce      : 00800000021201000012345678
IVI NID            : 5e
CTL TTL            : 80
SEQ                : 000002
SRC                : 1201
DST                : 2345
TransportPDU       : 0100
NetMIC Size        : 64 bits
EncDST || EncTransportPDU : b0e5d0ad
NetMIC             : 970d579a4e88051c

```

Obfuscation

```

Privacy Plaintext  : 00000000012345678b0e5d0ad970d57
PECB               : 04eba0902a0e
CTL || TTL || SEQ || SRC : 800000021201

NetworkPDU         : 5e84eba092380fb0e5d0ad970d579a4e88051c

```

8.3.5 Message #5

The Friend node confirms this friendship with a Friend Update message. The two nodes are now friends.

Transport Control Message

```

Opcode             : 02 (Friend Update)
  Flags            : 00
  IV Index         : 12345678
  MD               : 00

```

UpperTransportControlPDU

```

TTL                : 00
SEQ                : 014834
SRC                : 2345
DST                : 1201
UpperTransportPDU  : 001234567800

```

LowerTransportUnsegmentedControlPDU

```

CTL                : 01
TTL                : 00
SEQ                : 014834

```



```

SRC          : 2345
DST          : 1201
SEG          : 00
Opcode       : 02
Header       : 02
UpperTransportPDU : 001234567800
LowerTransportPDU : 02001234567800

```

NetworkPDU

```

IVindex      : 12345678
NetKey       : 7dd7364cd842ad18c17c2b820c84c3d6
LPNAddress   : 1201
FriendAddress : 2345
LPNCounter   : 0000
FriendCounter : 072f
CTL          : 01
TTL          : 00
SEQ          : 014834
SRC          : 2345
DST          : 1201
LowerTransportPDU : 02001234567800
NID          : 5e
EncryptionKey : be635105434859f484fc798e043ce40e
PrivacyKey    : 5d396d4b54d3cbafe943e051fe9a4eb8
Network Nonce : 00800148342345000012345678
IVI NID      : 5e
CTL TTL      : 80
SEQ          : 014834
SRC          : 2345
DST          : 1201
TransportPDU : 02001234567800
NetMIC Size   : 64 bits
EncDST || EncTransportPDU : 5c39da1792b1fee9ec
NetMIC        : 74b786c56d3a9dee

```

Obfuscation

```

Privacy Plaintext : 0000000000123456785c39da1792b1fe
PECB              : 2fd7bd08609e
CTL || TTL || SEQ || SRC : 800148342345

NetworkPDU        : 5eafd6f53c43db5c39da1792b1fee9ec74b786c56d3a9dee

```



8.3.6 Message #6

A Configuration Client sends a Config AppKey Add message to the Low Power node. This message is sent in two segments.

Access Payload

```

Opcode           : 00 (Config AppKey Add)
NetKeyIndex      : 123
AppKeyIndex      : 456
AppKey           : 63964771734fbd76e3b40519d1d94a48
Access Payload   : 0056341263964771734fbd76e3b40519d1d94a48

```

UpperTransportAccessPDU

```

IV Index         : 12345678
DevKey           : 9d6dd0e96eb25dc19a40ed9914f8f03f
TTL              : 04
SEQ              : 3129ab
SRC              : 0003
DST              : 1201
Application Nonce : 02003129ab0003120112345678
EncAccessPayload : ee9dddfd2169326d23f3afdfcfdc18c52fdef772
TransMIC Size    : 32 bits
TransMIC         : e0e17308
UpperTransportPDU : ee9dddfd2169326d23f3afdfcfdc18c52fdef772e0e17308
Segment#0        : ee9dddfd2169326d23f3afdf
Segment#1        : cfdc18c52fdef772e0e17308

```

LowerTransportSegmentedAccessPDU

```

CTL              : 00
TTL              : 04
SEQ              : 3129ab
SRC              : 0003
DST              : 1201
SEG              : 01
AKF              : 00
AID              : 00
SZMIC            : 00
SeqZero          : 9ab
SegO              : 00
SegN              : 01
Header           : 8026ac01
Segment#0        : ee9dddfd2169326d23f3afdf
LowerTransportPDU : 8026ac01ee9dddfd2169326d23f3afdf

```

NetworkPDU

```

IVindex           : 12345678
NetKey            : 7dd7364cd842ad18c17c2b820c84c3d6
CTL              : 00
TTL              : 04
SEQ              : 3129ab
SRC              : 0003
DST              : 1201
LowerTransportPDU : 8026ac01ee9dddfd2169326d23f3afdf
NID              : 68
EncryptionKey     : 0953fa93e7caac9638f58820220a398e
PrivacyKey        : 8b84eedec100067d670971dd2aa700cf
Network Nonce     : 00043129ab0003000012345678
IVI NID          : 68
CTL TTL          : 04
SEQ              : 3129ab
SRC              : 0003
DST              : 1201
TransportPDU      : 8026ac01ee9dddfd2169326d23f3afdf
NetMIC Size       : 32 bits
EncDST || EncTransportPDU : 0afba8c63d4e686364979deaf4fd40961145
NetMIC            : 939cda0e

```

Obfuscation

```

Privacy Plaintext : 0000000000123456780afba8c63d4e68
PECB              : ce84ec9f8a20
CTL || TTL || SEQ || SRC : 043129ab0003

NetworkPDU        : 68cab5c5348a230afba8c63d4e686364979deaf4fd40961145939cda0e

```

LowerTransportSegmentedAccessPDU

```

CTL      : 00
TTL      : 04
SEQ      : 3129ac
SRC      : 0003
DST      : 1201
SEG      : 01
AKF      : 00
AID      : 00
SZMIC    : 00
SeqZero  : 3129ab
SegO     : 01
SegN     : 01
Header   : 8026ac21
Segment#1 : cfdc18c52fdef772e0e17308

```



```

LowerTransportPDU      : 8026ac21cfdc18c52fdef772e0e17308

NetworkPDU

IVindex                : 12345678
NetKey                 : 7dd7364cd842ad18c17c2b820c84c3d6
CTL                   : 00
TTL                   : 04
SEQ                   : 3129ac
SRC                   : 0003
DST                   : 1201
LowerTransportPDU      : 8026ac21cfdc18c52fdef772e0e17308
NID                   : 68
EncryptionKey          : 0953fa93e7caac9638f58820220a398e
PrivacyKey             : 8b84eedec100067d670971dd2aa700cf
NetworkNonce           : 00043129ac0003000012345678
IVI NID               : 68
CTL TTL               : 04
SEQ                   : 3129ac
SRC                   : 0003
DST                   : 1201
TransportPDU           : 8026ac21cfdc18c52fdef772e0e17308
NetMIC Size           : 32 bits
EncDST || EncTransportPDU : 6cae0c032bf0746f44f1b8cc8ce5edc57e55
NetMIC                 : beed49c0

Obfuscation

Privacy Plaintext      : 0000000000123456786cae0c032bf074
PECB                  : 12249c714a87
CTL || TTL || SEQ || SRC : 043129ac0003

NetworkPDU             : 681615b5dd4a846cae0c032bf0746f44f1b8cc8ce5edc57e55beed49c0

```

8.3.7 Message #7

A friend of the destination acknowledges only one of the segments.

Transport Control Message

```

Opcode                : 00 (Segment Acknowledgment)
  OBO                  : 01
  SeqZero              : 09ab
  BlockAck             : 00000002

```

UpperTransportControlPDU

```

TTL                   : 0b
SEQ                   : 014835

```



SRC : 2345
 DST : 0003
 UpperTransportPDU : a6ac00000002

LowerTransportUnsegmentedControlPDU

CTL : 01
 TTL : 0b
 SEQ : 014835
 SRC : 2345
 DST : 0003
 SEG : 00
 Opcode : 00
 Header : 00
 UpperTransportPDU : a6ac00000002
 LowerTransportPDU : 00a6ac00000002

NetworkPDU

IVindex : 12345678
 NetKey : 7dd7364cd842ad18c17c2b820c84c3d6
 CTL : 01
 TTL : 0b
 SEQ : 014835
 SRC : 2345
 DST : 0003
 LowerTransportPDU : 00a6ac00000002
 NID : 68
 EncryptionKey : 0953fa93e7caac9638f58820220a398e
 PrivacyKey : 8b84eedec100067d670971dd2aa700cf
 Network Nonce : 008b0148352345000012345678
 IVI NID : 68
 CTL TTL : 8b
 SEQ : 014835
 SRC : 2345
 DST : 0003
 TransportPDU : 00a6ac00000002
 NetMIC Size : 64 bits
 EncDST || EncTransportPDU : 0d0d730f94d7f3509d
 NetMIC : f987bb417eb7c05f

Obfuscation

Privacy Plaintext : 0000000000123456780d0d730f94d7f3
 PECB : 6f77fd62bfdd
 CTL || TTL || SEQ || SRC : 8b0148352345
 NetworkPDU : 68e476b5579c980d0d730f94d7f3509df987bb417eb7c05f



8.3.8 Message #8

The Configuration Client receives the segment acknowledgment and retransmits the unacknowledged segment.

```

NID : 68
EncryptionKey : 0953fa93e7caac9638f58820220a398e
PrivacyKey : 8b84eedec100067d670971dd2aa700cf
Network Nonce : 00043129ad0003000012345678
IVI NID : 68
CTL TTL : 04
SEQ : 3129ad
SRC : 0003
DST : 1201
TransportPDU : 8026ac01ee9dddfd2169326d23f3afdf
NetMIC Size : 32 bits
EncDST || EncTransportPDU : 0e2f91add6f06e66006844cec97f973105ae
NetMIC : 2534f958

```

Obfuscation

```

Privacy Plaintext : 0000000000123456780e2f91add6f06e
PECB : 499b4bcac2cc
CTL || TTL || SEQ || SRC : 043129ad0003
NetworkPDU : 684daa6267c2cf0e2f91add6f06e66006844cec97f973105ae2534f958

```

8.3.9 Message #9

The Friend node receives this last segment and sends an acknowledgment of this last segment.

Transport Control Message

```

Opcode : 00 (Segment Acknowledgment)
OBO : 01
SeqZero : 09ab
BlockAck : 00000003

```

UpperTransportControlPDU

```

TTL : 0b
SEQ : 014836
SRC : 2345
DST : 0003
UpperTransportPDU : a6ac00000003

```

LowerTransportUnsegmentedControlPDU

```

CTL : 01
TTL : 0b

```

```

SEQ                : 014836
SRC                : 2345
DST                : 0003
SEG                : 00
Opcode             : 00
Header             : 00
UpperTransportPDU  : a6ac00000003
LowerTransportPDU  : 00a6ac00000003

```

NetworkPDU

```

IVindex            : 12345678
NetKey              : 7dd7364cd842ad18c17c2b820c84c3d6
CTL                : 01
TTL                : 0b
SEQ                : 014836
SRC                : 2345
DST                : 0003
LowerTransportPDU  : 00a6ac00000003
NID                : 68
EncryptionKey       : 0953fa93e7caac9638f58820220a398e
PrivacyKey          : 8b84eedec100067d670971dd2aa700cf
Network Nonce       : 008b0148362345000012345678
IVI NID            : 68
CTL TTL            : 8b
SEQ                : 014836
SRC                : 2345
DST                : 0003
TransportPDU        : 00a6ac00000003
NetMIC Size         : 64 bits
EncDST || EncTransportPDU : d85d806bbbed248614f
NetMIC              : 938067b0d983bb7b

```

Obfuscation

```

Privacy Plaintext   : 000000000012345678d85d806bbbed248
PECB                : 25c52fdb6a44
CTL || TTL || SEQ || SRC : 8b0148362345

NetworkPDU          : 68aec467ed4901d85d806bbbed248614f938067b0d983bb7b

```

8.3.10 Message #10

Sometime later, the Low Power node polls its Friend node to check for more stored messages.

Transport Control Message

```

Opcode             : 01 (Friend Poll)
FSN                 : 1

```



UpperTransportControlPDU

TTL : 00
 SEQ : 000003
 SRC : 1201
 DST : 2345
 UpperTransportPDU : 01

LowerTransportUnsegmentedControlPDU

CTL : 01
 TTL : 00
 SEQ : 000003
 SRC : 1201
 DST : 2345
 SEG : 00
 Opcode : 01
 Header : 01
 UpperTransportPDU : 01
 LowerTransportPDU : 0101

NetworkPDU

IVindex : 12345678
 NetKey : 7dd7364cd842ad18c17c2b820c84c3d6
 LPNAddress : 1201
 FriendAddress : 2345
 LPNCounter : 0000
 FriendCounter : 072f
 CTL : 01
 TTL : 00
 SEQ : 000003
 SRC : 1201
 DST : 2345
 LowerTransportPDU : 0101
 NID : 5e
 EncryptionKey : be635105434859f484fc798e043ce40e
 PrivacyKey : 5d396d4b54d3cbafe943e051fe9a4eb8
 Network Nonce : 00800000031201000012345678
 IVI NID : 5e
 CTL TTL : 80
 SEQ : 000003
 SRC : 1201
 DST : 2345
 TransportPDU : 0101
 NetMIC Size : 64 bits
 EncDST || EncTransportPDU : 7777ed35



```

NetMIC                               : 5afaf66d899c1e3d

Obfuscation

Privacy Plaintext                    : 000000000012345678777ed355afaf6
PECB                                : fb78656b679e
CTL|TTL|SEQ|SRC                     : 800000031201

NetworkPDU                          : 5e7b786568759f777ed355afaf66d899c1e3d

```

8.3.11 Message #11

The Friend node responds to this poll with the first segment of the stored message. It also indicates that it has more data.

```

NID                                  : 5e
EncryptionKey                       : be635105434859f484fc798e043ce40e
PrivacyKey                          : 5d396d4b54d3cbafe943e051fe9a4eb8
Network Nonce                       : 00033129ad0003000012345678
IVI NID                             : 5e
CTL TTL                             : 03
SEQ                                 : 3129ad
SRC                                 : 0003
DST                                 : 1201
TransportPDU                        : c026ac01ee9dddfd2169326d23f3afdf
NetMIC Size                         : 32 bits
EncDST || EncTransportPDU          : d5e748a20ecfd98ddfd32de80befb400213d
NetMIC                             : 113813b5

Obfuscation

Privacy Plaintext                    : 000000000012345678d5e748a20ecfd9
PECB                                : 6d8ee98cedf6
CTL|TTL|SEQ|SRC                     : 033129ad0003
NetworkPDU                          : 5e6ebfc021edf5d5e748a20ecfd98ddfd32de80befb400213d113813b5

```

8.3.12 Message #12

The Low Power node didn't receive that message, so polls again for the same message with the FSN value having the same value as last time.

Transport Control Message

```

Opcode                             : 01 (Friend Poll)
FSN                                : 1

```

UpperTransportControlPDU

TTL : 00
 SEQ : 000004
 SRC : 1201
 DST : 2345
 UpperTransportPDU : 01

LowerTransportUnsegmentedControlPDU

CTL : 01
 TTL : 00
 SEQ : 000004
 SRC : 1201
 DST : 2345
 SEG : 00
 Opcode : 01
 Header : 01
 UpperTransportPDU : 01
 LowerTransportPDU : 0101

NetworkPDU

IVindex : 12345678
 NetKey : 7dd7364cd842ad18c17c2b820c84c3d6
 LPNAddress : 1201
 FriendAddress : 2345
 LPNCounter : 0000
 FriendCounter : 072f
 CTL : 01
 TTL : 00
 SEQ : 000004
 SRC : 1201
 DST : 2345
 LowerTransportPDU : 0101
 NID : 5e
 EncryptionKey : be635105434859f484fc798e043ce40e
 PrivacyKey : 5d396d4b54d3cbafe943e051fe9a4eb8
 Network Nonce : 00800000041201000012345678
 IVI NID : 5e
 CTL TTL : 80
 SEQ : 000004
 SRC : 1201
 DST : 2345
 TransportPDU : 0101
 NetMIC Size : 64 bits
 EncDST || EncTransportPDU : ae214660
 NetMIC : 87599c2426ce9a35



Obfuscation

```

Privacy Plaintext      : 000000000012345678ae21466087599c
PECB                  : 0a18fc6a5f04
CTL|TTL|SEQ|SRC       : 800000041201

NetworkPDU            : 5e8a18fc6e4d05ae21466087599c2426ce9a35

```

8.3.13 Message #13

The Friend node responds with the same message as last time.

```

NID                   : 5e
EncryptionKey         : be635105434859f484fc798e043ce40e
PrivacyKey            : 5d396d4b54d3cbafe943e051fe9a4eb8
Network Nonce         : 00033129ad0003000012345678
IVI NID               : 5e
CTL TTL              : 03
SEQ                   : 3129ad
SRC                   : 0003
DST                   : 1201
TransportPDU          : c026ac01ee9dddfd2169326d23f3afdf
NetMIC Size           : 32 bits
EncDST || EncTransportPDU : d5e748a20ecfd98ddfd32de80befb400213d
NetMIC                : 113813b5

```

Obfuscation

```

Privacy Plaintext      : 000000000012345678d5e748a20ecfd9
PECB                  : 6d8ee98cedf6
CTL|TTL|SEQ|SRC       : 033129ad0003

NetworkPDU            : 5e6ebfc021edf5d5e748a20ecfd98ddfd32de80befb400213d113813b5

```

8.3.14 Message #14

The Low Power node received the retransmitted stored message. Because that message is not a Friend Update with the MD field set to 0, it sends another Friend Poll to obtain the next message.

Transport Control Message

```

Opcode                : 01 (Friend Poll)
FSN                   : 0

```

UpperTransportControlPDU

```

TTL                   : 00
SEQ                   : 000005

```



SRC : 1201
 DST : 2345
 UpperTransportPDU : 00

LowerTransportUnsegmentedControlPDU

CTL : 01
 TTL : 00
 SEQ : 000005
 SRC : 1201
 DST : 2345
 SEG : 00
 Opcode : 01
 Header : 01
 UpperTransportPDU : 00
 LowerTransportPDU : 0100

NetworkPDU

IVindex : 12345678
 NetKey : 7dd7364cd842ad18c17c2b820c84c3d6
 LPNAddress : 1201
 FriendAddress : 2345
 LPNCounter : 0000
 FriendCounter : 072f
 CTL : 01
 TTL : 00
 SEQ : 000005
 SRC : 1201
 DST : 2345
 LowerTransportPDU : 0100
 NID : 5e
 EncryptionKey : be635105434859f484fc798e043ce40e
 PrivacyKey : 5d396d4b54d3cbafe943e051fe9a4eb8
 Network Nonce : 00800000051201000012345678
 IVI NID : 5e
 CTL TTL : 80
 SEQ : 000005
 SRC : 1201
 DST : 2345
 TransportPDU : 0100
 NetMIC Size : 64 bits
 EncDST || EncTransportPDU : 7d3ae62a
 NetMIC : 3c75dff683dce24e



Obfuscation

```

Privacy Plaintext      : 0000000000123456787d3ae62a3c75df
PECB                   : 8bbaf92e4e8e
CTL|TTL|SEQ|SRC        : 800000051201

NetworkPDU             : 5e0bbaf92b5c8f7d3ae62a3c75dff683dce24e

```

8.3.15 Message #15

The Friend node responds with the next message in the friend queue. The Friend node has no more data, so the next time the Low Power node sends a Friend Poll message, the Friend will respond with a Friend Update message that has the MD field set to 0.

```

NID                    : 5e
EncryptionKey          : be635105434859f484fc798e043ce40e
PrivacyKey             : 5d396d4b54d3cbafe943e051fe9a4eb8
Network Nonce          : 00033129ac0003000012345678
IVI NID                : 5e
CTL TTL               : 03
SEQ                   : 3129ac
SRC                   : 0003
DST                   : 1201
TransportPDU          : 8026ac21cfdc18c52fdef772e0e17308
NetMIC Size           : 32 bits
EncDST || EncTransportPDU : f1d29805664d235eacd707217dedfe78497f
NetMIC                : efec7391

```

Obfuscation

```

Privacy Plaintext      : 000000000012345678f1d29805664d23
PECB                   : abeb9ca27ee4
CTL|TTL|SEQ|SRC        : 033129ac0003
NetworkPDU             : 5ea8dab50e7ee7f1d29805664d235eacd707217dedfe78497fefec7391

```

8.3.16 Message #16

The Low Power node has now received the complete Config AppKey Add message, so it responds to the segmented message with a status message. This is sent directly to the Configuration Client.

Access Payload

```

Opcode                : 8003 (Config AppKey Status)
Status                : 00
NetKeyIndex           : 123
AppKeyIndex           : 456
Access Payload        : 800300563412

```


UpperTransportAccessPDU

IV Index	: 12345678
DevKey	: 9d6dd0e96eb25dc19a40ed9914f8f03f
TTL	: 0b
SEQ	: 000006
SRC	: 1201
DST	: 0003
Application Nonce	: 02000000061201000312345678
EncAccessPayload	: 89511bf1d1a8
TransMIC Size	: 32 bits
TransMIC	: 1c11dcef
UpperTransportPDU	: 89511bf1d1a81c11dcef

LowerTransportUnsegmentedAccessPDU

CTL	: 00
TTL	: 0b
SEQ	: 000006
SRC	: 1201
DST	: 0003
SEG	: 00
AKF	: 00
AID	: 00
Header	: 00
UpperTransportPDU	: 89511bf1d1a81c11dcef
LowerTransportPDU	: 0089511bf1d1a81c11dcef

NetworkPDU

IVindex	: 12345678
NetKey	: 7dd7364cd842ad18c17c2b820c84c3d6
CTL	: 00
TTL	: 0b
SEQ	: 000006
SRC	: 1201
DST	: 0003
LowerTransportPDU	: 0089511bf1d1a81c11dcef
NID	: 68
EncryptionKey	: 0953fa93e7caac9638f58820220a398e
PrivacyKey	: 8b84eedec100067d670971dd2aa700cf
Network Nonce	: 000b0000061201000012345678
IVI NID	: 68
CTL TTL	: 0b
SEQ	: 000006
SRC	: 1201
DST	: 0003
TransportPDU	: 0089511bf1d1a81c11dcef



```

NetMIC Size           : 32 bits
EncDST || EncTransportPDU : 6b9be7f5a642f2f98680e61c3a
NetMIC                : 8b47f228

Obfuscation

Privacy Plaintext      : 0000000000123456786b9be7f5a64287
PECB                   : b037280f9de9
CTL || TTL || SEQ || SRC : 0b0000061201

NetworkPDU             : 68e80e5da5af0e6b9be7f5a642f2f98680e61c3a8b47f228

```

8.3.17 Message #17

A Relay node receives the message from the Low Power node and relays it, decrementing the TTL value.

```

NID                    : 68
EncryptionKey          : 0953fa93e7caac9638f58820220a398e
PrivacyKey             : 8b84eedec100067d670971dd2aa700cf
Network Nonce          : 000a0000061201000012345678
IVI NID                : 68
CTL TTL               : 0a
SEQ                    : 000006
SRC                    : 1201
DST                    : 0003
TransportPDU           : 0089511bf1d1a81c11dcef
NetMIC Size            : 32 bits
EncDST || EncTransportPDU : 2a80d381b91f824dd4f0a3cd54
NetMIC                 : cea23b7a

Obfuscation

Privacy Plaintext      : 0000000000123456782a80d381b91f82
PECB                   : b8bd2c18096e
CTL || TTL || SEQ || SRC : 0a0000061201
NetworkPDU             : 68b2bd2c1e1b6f2a80d381b91f824dd4f0a3cd54cea23b7a

```

8.3.18 Message #18

The Low Power node sends a Health Current Status message indicating that there are no faults.

Access Payload

```

Opcode                : 04 (Health Current Status)
TestID:               : 00
CompanyID             : 0000
Faults                : 00
Access Payload        : 0400000000

```

UpperTransportAccessPDU

IV Index	: 12345678
AppKey	: 63964771734fbd76e3b40519d1d94a48
TTL	: 03
SEQ	: 000007
SRC	: 1201
DST	: ffff
Application Nonce	: 01000000071201ffff12345678
EncAccessPayload	: 5a8bde6d91
TransMIC Size	: 32 bits
TransMIC	: 06ea078a
UpperTransportPDU	: 5a8bde6d9106ea078a

LowerTransportUnsegmentedAccessPDU

CTL	: 00
TTL	: 03
SEQ	: 000007
SRC	: 1201
DST	: ffff
SEG	: 00
AKF	: 01
AID	: 26
Header	: 66
UpperTransportPDU	: 5a8bde6d9106ea078a
LowerTransportPDU	: 665a8bde6d9106ea078a

NetworkPDU

IVindex	: 12345678
NetKey	: 7dd7364cd842ad18c17c2b820c84c3d6
CTL	: 00
TTL	: 03
SEQ	: 000007
SRC	: 1201
DST	: ffff
LowerTransportPDU	: 665a8bde6d9106ea078a
NID	: 68
EncryptionKey	: 0953fa93e7caac9638f58820220a398e
PrivacyKey	: 8b84eedec100067d670971dd2aa700cf
Network Nonce	: 00030000071201000012345678
IVI NID	: 68
CTL TTL	: 03
SEQ	: 000007
SRC	: 1201
DST	: ffff
TransportPDU	: 665a8bde6d9106ea078a



```

NetMIC Size           : 32 bits
EncDST || EncTransportPDU : 5673728a627fb938535508e2
NetMIC                : 1a6baf57

```

Obfuscation

```

Privacy Plaintext      : 0000000000123456785673728a627fb9
PECB                   : 4bcba430940f
CTL || TTL || SEQ || SRC : 030000071201

NetworkPDU             : 6848cba437860e5673728a627fb938535508e21a6baf57

```

8.3.19 Message #19

The Low Power node sends another Health Current Status message indicating that there are three faults: Battery Low Warning, Power Supply Interrupted Warning, and Supply Voltage Too Low Warning.

Access Payload

```

Opcode                : 04 (Health Current Status)
TestID                : 00
CompanyID              : 0000
Faults                : 010703
Access Payload        : 04000000010703

```

UpperTransportAccessPDU

```

IV Index              : 12345678
AppKey                : 63964771734fbd76e3b40519d1d94a48
TTL                   : 03
SEQ                   : 000009
SRC                   : 1201
DST                   : ffff
Application Nonce      : 01000000091201ffff12345678
EncAccessPayload      : ca6cd88e698d12
TransMIC Size         : 32 bits
TransMIC              : 65f43fc5
UpperTransportPDU     : ca6cd88e698d1265f43fc5

```

LowerTransportSegmentedAccessPDU

```

CTL                   : 00
TTL                   : 03
SEQ                   : 000009
SRC                   : 1201
DST                   : ffff
SEG                   : 01
AKF                   : 01
AID                   : 26

```



```

UpperTransportPDU      : ca6cd88e698d1265f43fc5
LowerTransportPDU      : 66ca6cd88e698d1265f43fc5

NetworkPDU

IVindex                : 12345678
NetKey                 : 7dd7364cd842ad18c17c2b820c84c3d6
CTL                   : 00
TTL                   : 03
SEQ                   : 000009
SRC                   : 1201
DST                   : ffff
LowerTransportPDU      : 66ca6cd88e698d1265f43fc5
NID                   : 68
EncryptionKey          : 0953fa93e7caac9638f58820220a398e
PrivacyKey             : 8b84eedec100067d670971dd2aa700cf
Network Nonce          : 00030000091201000012345678
IVI NID               : 68
CTL TTL               : 03
SEQ                   : 000009
SRC                   : 1201
DST                   : ffff
TransportPDU           : 66ca6cd88e698d1265f43fc5
NetMIC Size            : 32 bits
EncDST || EncTransportPDU : 3010a05e1b23a926023da75d25ba
NetMIC                 : 91793736

Obfuscation

Privacy Plaintext      : 0000000000123456783010a05e1b23a9
PECB                  : 120edee5ca3d
CTL || TTL || SEQ || SRC : 030000091201

NetworkPDU             : 68110edeecd83c3010a05e1b23a926023da75d25ba91793736

```

8.3.20 Message #20

The Low Power node sends the Health Current Status message with the same three faults.

Access Payload

```

Opcode                : 04 (Health Current Status)
TestID                : 00
CompanyID             : 0000
Faults                : 010703
Access Payload        : 04000000010703

```

UpperTransportAccessPDU

IV Index	: 12345677
AppKey	: 63964771734fbd76e3b40519d1d94a48
TTL	: 03
SEQ	: 070809
SRC	: 1234
DST	: ffff
Application Nonce	: 01000708091234ffff12345677
EncAccessPayload	: 9c9803e110fea9
TransMIC Size	: 32 bits
TransMIC	: 29e9542d
UpperTransportPDU	: 9c9803e110fea929e9542d

LowerTransportSegmentedAccessPDU

CTL	: 00
TTL	: 03
SEQ	: 070809
SRC	: 1234
DST	: ffff
SEG	: 01
AKF	: 01
AID	: 26
Header	: 66
Segment#0	: 9c9803e110fea929e9542d
LowerTransportPDU	: 669c9803e110fea929e9542d

NetworkPDU

IVindex	: 12345677
NetKey	: 7dd7364cd842ad18c17c2b820c84c3d6
CTL	: 00
TTL	: 03
SEQ	: 070809
SRC	: 1234
DST	: ffff
LowerTransportPDU	: 669c9803e110fea929e9542d
NID	: 68
EncryptionKey	: 0953fa93e7caac9638f58820220a398e
PrivacyKey	: 8b84eedec100067d670971dd2aa700cf
Network Nonce	: 00030708091234000012345677
IVI NID	: e8
CTL TTL	: 03
SEQ	: 070809
SRC	: 1234
DST	: ffff
TransportPDU	: 669c9803e110fea929e9542d



```

NetMIC Size           : 32 bits
EncDST || EncTransportPDU : 8c3dc87344a16c787f6b08cc897c
NetMIC                : 941a5368

```

Obfuscation

```

Privacy Plaintext      : 0000000000123456778c3dc87344a16c
PECB                   : 5fcd59ebfaad
CTL || TTL || SEQ || SRC : 030708091234

NetworkPDU             : e85cca51e2e8998c3dc87344a16c787f6b08cc897c941a5368

```

8.3.21 Message #21

The Low Power node sends a vendor command to a group address.

Company ID: 0x000A - Cambridge Silicon Radio (See Bluetooth Assigned Numbers)
Vendor Opcode: 0x15

Access Payload

```

Opcode                : 0x15 : 0x000a (Opcode 15 : Company ID 000a)
Params                : 48656c6c6f
Access Payload        : d50a0048656c6c6f

```

UpperTransportAccessPDU

```

IV Index              : 12345677
AppKey                : 63964771734fbd76e3b40519d1d94a48
TTL                   : 03
SEQ                   : 07080a
SRC                   : 1234
DST                   : c105
Application Nonce      : 010007080a1234c10512345677
EncAccessPayload       : 4d92e9dfcf3ab85b
TransMIC Size         : 32 bits
TransMIC              : 6e8fcf03
UpperTransportPDU      : 4d92e9dfcf3ab85b6e8fcf03

```

LowerTransportUnsegmentedAccessPDU

```

CTL                   : 00
TTL                   : 03
SEQ                   : 07080a
SRC                   : 1234
DST                   : c105
SEG                   : 00
AKF                   : 01
AID                   : 26

```



```

Header                : 66
UpperTransportPDU     : 4d92e9dfcf3ab85b6e8fcf03
LowerTransportPDU     : 664d92e9dfcf3ab85b6e8fcf03

NetworkPDU

IVindex               : 12345677
NetKey                : 7dd7364cd842ad18c17c2b820c84c3d6
CTL                  : 00
TTL                  : 03
SEQ                  : 07080a
SRC                  : 1234
DST                  : c105
LowerTransportPDU     : 664d92e9dfcf3ab85b6e8fcf03
NID                  : 68
EncryptionKey         : 0953fa93e7caac9638f58820220a398e
PrivacyKey            : 8b84eedec100067d670971dd2aa700cf
Network Nonce         : 000307080a1234000012345677
IVI NID              : e8
CTL TTL              : 03
SEQ                  : 07080a
SRC                  : 1234
DST                  : c105
TransportPDU          : 664d92e9dfcf3ab85b6e8fcf03
NetMIC Size           : 32 bits
EncDST || EncTransportPDU : a4d61157bb76352ea6307eebfe0f30
NetMIC                : b83500e9

Obfuscation

Privacy Plaintext     : 000000000012345677a4d61157bb7635
PECB                  : 4d88b60a2d6c
CTL || TTL || SEQ || SRC : 0307080a1234

NetworkPDU            : e84e8fbe003f58a4d61157bb76352ea6307eebfe0f30b83500e9

```

8.3.22 Message #22

The Low Power node sends a vendor command to a virtual address.

Access Payload

```

Opcode                : 15 : 000a (Vendor 15 : 000a)
Params                : 48656c6c6f
Access Payload        : d50a0048656c6c6f

```

UpperTransportAccessPDU




```

IV Index          : 12345677
AppKey            : 63964771734fbd76e3b40519d1d94a48
TTL               : 03
SEQ               : 07080b
SRC               : 1234
Label UUID        : 0073e7e4d8b9440faf8415df4c56c0e1
DST (Virtual Address) : b529
Application Nonce  : 010007080b1234b52912345677
EncAccessPayload   : 3871b904d4315263
TransMIC Size      : 32 bits
TransMIC           : 16ca48a0
UpperTransportPDU  : 3871b904d431526316ca48a0

```

LowerTransportUnsegmentedAccessPDU

```

CTL               : 00
TTL               : 03
SEQ               : 07080b
SRC               : 1234
DST               : b529
SEG               : 00
AKF               : 01
AID               : 26
Header            : 66
UpperTransportPDU : 3871b904d431526316ca48a0
LowerTransportPDU : 663871b904d431526316ca48a0

```

NetworkPDU

```

IVindex           : 12345677
NetKey            : 7dd7364cd842ad18c17c2b820c84c3d6
CTL               : 00
TTL               : 03
SEQ               : 07080b
SRC               : 1234
DST               : b529
LowerTransportPDU : 343871b904d431526316ca48a0
NID               : 68
EncryptionKey      : 0953fa93e7caac9638f58820220a398e
PrivacyKey         : 8b84eedec100067d670971dd2aa700cf
Network Nonce      : 000307080b1234000012345677
IVI NID           : e8
CTL TTL           : 03
SEQ               : 07080b
SRC               : 1234
DST               : b529
TransportPDU       : 663871b904d431526316ca48a0
NetMIC Size        : 32 bits

```

```
EncDST || EncTransportPDU : ed31f3fdcf88a411135fea55df730b
NetMIC : 6b28e255
```

Obfuscation

```
Privacy Plaintext : 00000000012345677ed31f3fdcf88a4
PECB : db5ba6c5e3d7
CTL|TTL|SEQ|SRC : 0307080b1234

NetworkPDU : e8d85caecef1e3ed31f3fdcf88a411135fea55df730b6b28e255
```

8.3.23 Message #23

The Low Power node sends a vendor command to a different virtual address.

Access Payload

```
Opcode : 15 : 000a (Vendor 15 : 000a)
Params : 48656c6c6f
Access Payload : d50a0048656c6c6f
```

UpperTransportAccessPDU

```
IV Index : 12345677
AppKey : 63964771734fbd76e3b40519d1d94a48
TTL : 03
SEQ : 07080c
SRC : 1234
Label UUID : f4a002c7fb1e4ca0a469a021de0db875
DST (Virtual Address) : 9736
Application Nonce : 010007080c1234973612345677
EncAccessPayload : 2456db5e3100eef6
TransMIC Size : 32 bits
TransMIC : 5daa7a38
UpperTransportPDU : 2456db5e3100eef65daa7a38
```

LowerTransportUnsegmentedAccessPDU

```
CTL : 00
TTL : 03
SEQ : 07080c
SRC : 1234
DST : 9736
SEG : 00
AKF : 01
AID : 26
Header : 66
UpperTransportPDU : 2456db5e3100eef65daa7a38
LowerTransportPDU : 662456db5e3100eef65daa7a38
```

NetworkPDU

```

IVindex           : 12345677
NetKey            : 7dd7364cd842ad18c17c2b820c84c3d6
CTL               : 00
TTL               : 03
SEQ               : 07080c
SRC               : 1234
DST               : 9736
LowerTransportPDU : 342456db5e3100eef65daa7a38
NID               : 68
EncryptionKey     : 0953fa93e7caac9638f58820220a398e
PrivacyKey        : 8b84eedec100067d670971dd2aa700cf
Network Nonce     : 000307080c1234000012345677
IVI NID           : e8
CTL TTL           : 03
SEQ               : 07080c
SRC               : 1234
DST               : 9736
TransportPDU      : 662456db5e3100eef65daa7a38
NetMIC Size       : 32 bits
EncDST || EncTransportPDU : 7a9d696d3dd16a75489696f0b70c71
NetMIC            : 1b881385

```

Obfuscation

```

Privacy Plaintext : 0000000000123456777a9d696d3dd16a
PECB              : 74a385d9ec19
CTL || TTL || SEQ || SRC : 0307080c1234

NetworkPDU        : e877a48dd5fe2d7a9d696d3dd16a75489696f0b70c711b881385

```

8.3.24 Message #24

The Low Power node sends a vendor command to a virtual address using a 64-bit TransMIC.

Company ID: 0x000A – Cambridge Silicon Radio (See Bluetooth Assigned Numbers)
 Vendor Opcode: 0x2A

Access Payload

```

Vendor Opcode      : 0x2A : 0x000A (Opcode 2a : Company ID 000a)
Params             : 576f726c64
Access Payload     : ea0a00576f726c64

```

UpperTransportAccessPDU

```

IV Index          : 12345677

```



```

AppKey                : 63964771734fbd76e3b40519d1d94a48
TTL                   : 03
SEQ                   : 07080d
SRC                   : 1234
Label UUID            : f4a002c7fb1e4ca0a469a021de0db875
DST (Virtual Address) : 9736
Application Nonce     : 018007080d1234973612345677
EncAccessPayload      : c3c51d8e476b28e3
TransMIC Size         : 64 bits
TransMIC              : aa5001f31c01cea6
UpperTransportPDU     : c3c51d8e476b28e3aa5001f31c01cea6
Segment#0             : c3c51d8e476b28e3aa5001f3
Segment#1             : 1c01cea6

```

LowerTransportSegmentedAccessPDU

```

CTLi                 : 00
TTL                  : 03
SEQ                  : 07080d
SRC                  : 1234
DST                  : 9736
SEG                  : 01
AKF                  : 01
AID                  : 26
SZMIC                : 01
SeqZero              : 80d
SegO                  : 00
SegN                  : 01
Header               : e6a03401
Segment#0            : c3c51d8e476b28e3aa5001f3
LowerTransportPDU    : e6a03401c3c51d8e476b28e3aa5001f3

```

NetworkPDU

```

IVindex              : 12345677
NetKey                : 7dd7364cd842ad18c17c2b820c84c3d6
CTL                   : 00
TTL                   : 03
SEQ                   : 07080d
SRC                   : 1234
DST                   : 9736
LowerTransportPDU    : e6a03401c3c51d8e476b28e3aa5001f3
NID                   : 68
EncryptionKey         : 0953fa93e7caac9638f58820220a398e
PrivacyKey            : 8b84eedec100067d670971dd2aa700cf
Network Nonce         : 000307080d1234000012345677
IVI NID               : e8
CTL TTL              : 03

```



```

SEQ          : 07080d
SRC          : 1234
DST          : 9736
TransportPDU : e6a03401c3c51d8e476b28e3aa5001f3
NetMIC Size  : 32 bits
EncDST || EncTransportPDU : 94e998b4081f47a35251fdd3896d99e4db48
NetMIC       : 9b918599

```

Obfuscation

```

Privacy Plaintext : 00000000001234567794e998b4081f47
PECB              : 61496db69e23
CTL || TTL || SEQ || SRC : 0307080d1234

NetworkPDU        : e8624e65bb8c1794e998b4081f47a35251fdd3896d99e4db489b918599

```

LowerTransportSegmentedAccessPDU

```

CTL      : 00
TTL      : 03
SEQ      : 07080e
SRC      : 1234
DST      : 9736
SEG      : 01
AKF      : 01
AID      : 26
SZMIC    : 01
SeqZero  : 80d
Seg0     : 01
SegN     : 01
Header   : e6a03421
Segment#1 : 1c01cea6
LowerTransportPDU : e6a034211c01cea6

```

NetworkPDU

```

IVindex      : 12345677
NetKey       : 7dd7364cd842ad18c17c2b820c84c3d6
CTL          : 00
TTL          : 03
SEQ          : 07080e
SRC          : 1234
DST          : 9736
LowerTransportPDU : e6a034211c01cea6
NID          : 68
EncryptionKey : 0953fa93e7caac9638f58820220a398e
PrivacyKey   : 8b84eedec100067d670971dd2aa700cf
Network Nonce : 000307080e1234000012345677

```

```

IVI NID          : e8
CTL TTL          : 03
SEQ              : 07080e
SRC              : 1234
DST              : 9736
TransportPDU     : e6a034211c01cea6
NetMIC Size      : 32 bits
EncDST || EncTransportPDU : dc2f4dd6fb4db33a6c08
NetMIC           : 8d023b47

```

Obfuscation

```

Privacy Plaintext : 000000000012345677dc2f4dd6fb4db3
PECB              : a4d7f8acf876
CTL|TTL|SEQ|SRC   : 0307080e1234

NetworkPDU        : e8a7d0f0a2ea42dc2f4dd6fb4db33a6c088d023b47

```

8.4 Beacon sample data

The following beacon sample data shows examples of beacons.

8.4.1 Unprovisioned device beacon (without URI)

This shows an example of an unprovisioned device. This device has some OOB information that is an ASCII-string written on a piece of paper and on the device itself.

```

Device UUID      : 70cf7c9732a345b691494810d2e9cbf4
OOB              : String, on piece of paper, on device
OOB Information  : a040

Beacon           : 0070cf7c9732a345b691494810d2e9cbf4a040

```

8.4.2 Unprovisioned device beacon (with URI)

This shows an example of an unprovisioned device that also includes some OOB information as a number on the inside of the manual, and also a URI-hash that can be used to help identify the device.

```

Device UUID      : 70cf7c9732a345b691494810d2e9cbf4
OOB              : Number, Inside Manual
OOB Information  : 4020
URI              : https://www.example.com/mesh/products/light-switch-v3
URI Data         : 172f2f777772e6578616d706c652e636f6d2f6d6573682f70726f6475637473
                  2f6c696768742d7377697463682d7633
URI Hash         : d97478b3667f4839487469c72b8e5e9e

Beacon           : 0070cf7c9732a345b691494810d2e9cbf44020d97478b3

```

8.4.3 Secure Network beacon

This shows an example of a Secure Network beacon that includes the IV Index for a given network key. There are now key refresh or IV updates occurring at this time.

```

IV Update Flag      : 0
Key Refresh Flag    : 0
NetKey              : 7dd7364cd842ad18c17c2b820c84c3d6
IV Index            : 12345678
Flags               : 00
Network ID          : 3ecaff672f673370
Message             : 003ecaff672f67337012345678
BeaconKey           : 5423d967da639a99cb02231a83f7d254
Authentication Value : 8ea261582f364f6f3c74ef80336ca17e

Beacon              : 01003ecaff672f673370123456788ea261582f364f6f

```

8.4.4 Secure Network beacon (IV update in progress)

This shows an example Secure Network beacon that would be sent when the IV Index is being updated. In this example, the IV Index has been incremented and the IV Update Flag is set.

```

IV Update Flag      : 1
Key Refresh Flag    : 0
NetKey              : 7dd7364cd842ad18c17c2b820c84c3d6
IV Index            : 12345679
Flags               : 02
Network ID          : 3ecaff672f673370
Message             : 023ecaff672f67337012345679
BeaconKey           : 5423d967da639a99cb02231a83f7d254
Authentication Value : c2af80ad072a135c28cf843369887039

Beacon              : 01023ecaff672f67337012345679c2af80ad072a135c

```

8.4.5 Secure Network beacon (IV update complete)

This shows an example of a Secure Network beacon after the IV Index has been updated. The IV Index has the same value as the previous Secure Network beacon, but the IV Update Flag is now cleared.

```

IV Update Flag      : 0
Key Refresh Flag    : 0
NetKey              : 7dd7364cd842ad18c17c2b820c84c3d6
IV Index            : 12345679
Flags               : 00
Network ID          : 3ecaff672f673370
Message             : 003ecaff672f67337012345679
BeaconKey           : 5423d967da639a99cb02231a83f7d254
Authentication Value : c62f09e4c957f59d96f506f64604bfc1

Beacon              : 01003ecaff672f67337012345679c62f09e4c957f59d

```

8.5 Provisioning Service sample data

The following sample data shows the advertising data for a Provisioning Service advertisement.

8.5.1 Mesh Provisioning Service advertising service data

This sample data shows that the device has some OOB information as a number that is printed inside of the manual.

```
Device UUID       : 70cf7c9732a345b691494810d2e9cbf4
OOB               : Number, Inside Manual
OOB Information   : 4020

Adv Len           : 15
Adv (Service Data) : 16
Mesh Provisioning UUID: 1827
Device UUID       : 70cf7c9732a345b691494810d2e9cbf4
OOB Information   : 4020
ADV Data          : 1516271870cf7c9732a345b691494810d2e9cbf44020
```

8.6 Mesh Proxy Service sample data

The following sample data shows Mesh Proxy service sample data.

8.6.1 Service data using Network ID

This shows the advertising data used to broadcast the Network ID of a network that can be accessed through a Mesh Proxy service. This would be used to allow a device to connect to a specific mesh network.

```
NetKey            : 7dd7364cd842ad18c17c2b820c84c3d6
Adv Len           : 0c
Adv (Service Data) : 16
Mesh Proxy UUID   : 1828
Type              : 00
Network ID        : 3ecaff672f673370
ADV Data          : 0c162818003ecaff672f673370
```

8.6.2 Service data using Node Identity

This shows the advertising data used to broadcast the identity of a node in a private manner that can be accessed through a Mesh Proxy service. This would be used to allow a device to connect to a specific node.

```
NetKey            : 7dd7364cd842ad18c17c2b820c84c3d6
Source Address    : 1201
Random            : 34ae608fbbc1f2c6
Nonce             : 0000000000034ae608fbbc1f2c61201
IdentityKey       : 84396c435ac48560b5965385253e210c
Adv Len           : 14
```



```

Adv (Service Data)      : 16
Mesh Proxy UUID         : 1828
Type                    : 01
Hash                    : 00861765aefcc57b
Random                  : 34ae608fbbc1f2c6
ADV Data                 : 141628180100861765aefcc57b34ae608fbbc1f2c6

```

8.7 PB-ADV provisioning sample data

The following sample data shows a complete set of provisioning transactions over PB-ADV. The following sample data is based on the provisioning and device private keys documented below.

```

Prov Private Key      : 06a516693c9aa31a6084545d0c5db641b48572b97203ddffb7ac73f7d0457663
Prov Public Key       : 2c31a47b5779809ef44cb5eaaaf5c3e43d5f8faad4a8794cb987e9b03745c78dd
                      : 919512183898dfbecd52e2408e43871fd021109117bd3ed4eaf8437743715d4f
Device Private Key    : 529aa0670d72cd6497502ed473502b037e8803b5c60829a5a3caa219505530ba
Device Public Key     : f465e43ff23d3f1b9dc7dfc04da8758184dbc966204796eccf0d6cf5e16500cc
                      : 0201d048bcbbd899eeefc424164e33c201c2b010ca6b4d43a8a155cad8ecb279
Prov ECDH             : ab85843a2f6d883f62e5684b38e307335fe6e1945ecd19604105c6f23221eb69
Device ECDH           : ab85843a2f6d883f62e5684b38e307335fe6e1945ecd19604105c6f23221eb69
Prov Random           : 8b19ac31d58b124c946209b5db1021b9
Device Random         : 55a2a2bca04cd32ff6f346bd0a0c1a3a

```

8.7.1 PB-ADV Link Open

The Provisioner, after receiving the Mesh Provisioning Service advertising data, will send a Link Open message including the Device UUID of the new device.

Link Open

```
Device UUID      : 70cf7c9732a345b691494810d2e9cbf4
```

Provisioning Control

```

LinkID          : 23af5850
Transaction     : 00
Opcode          : 00 (Link Open)
Message         : 23af5850000370cf7c9732a345b691494810d2e9cbf4

```

8.7.2 PB-ADV Link Ack

The new device will respond with a Link Ack to confirm that it is accepting this Link Open. All other messages after this point will use this LinkID to identify this session until the Link Close message is received.

Link Ack

Provisioning Control

```
LinkID          : 23af5850
```

```

Transaction      :      00
Opcode           : 01 (Link Ack)
Message          : 23af58500007

```

8.7.3 PB-ADV Provisioning Invite

The Provisioner will invite the new device to join the mesh network. This includes a duration for which the new device will attract attention of the user such that the user knows which new device is currently being provisioned. In this case, the duration is 0 seconds, meaning that the Provisioner didn't need the new device to make itself known to the user.

Provisioning Invite

```

Duration         : 00 (0 seconds)
Message          : 0000

LinkID           : 23af5850
Transaction      :      00

Segment0         : 0000
SegN             : 00
PDU Length       : 0002
FCS              : 14
Message0         : 23af5850000000002140000

```

8.7.3.1 PB-ADV Transaction Ack

The Provisioner acknowledges the invite transaction.

PBADV Transaction Acknowledge

```

LinkID           : 23af5850
Transaction      :      00
Message          : 23af58500001

```

8.7.4 PB-ADV Provisioning Capabilities

The new device responds to the invite by sending its capabilities. The new device has only one element, supports the mandatory P-256 algorithm, and has no OOB information or input or output capabilities.

Provisioning Capabilities

```

Num Elements     : 01
Algorithms       : 0001
Pub Key Type     : 00
Static OOB       : 00
Output OOB Size  : 00
Output OOB Action : 0000
Input OOB Size   : 00
Input Action     : 0000

```



```

Message          : 010100010000000000000000
LinkID           : 23af5850
Transaction      :      80

Segment0         : 010100010000000000000000
SegN             : 00
PDU Length       : 000c
FCS              : d6
Message0         : 23af58508000000cd601010001000000000000000

```

8.7.4.1 PB-ADV Transaction Ack

The Provisioner acknowledges the capabilities transaction.

PBADV Transaction Acknowledge

```

LinkID           : 23af5850
Transaction      :      80
Message          : 23af58508001

```

8.7.5 PB-ADV Provisioning Start

The Provisioner upon receiving the capabilities, sends a provisioning start message stating the algorithm and authentication method to use.

Provisioning Start

```

Algorithm         : 00
Pub Key Type      : 0000
Authentication Method : 00
Authentication Action : 00
Authentication Size : 00
Message          : 020000000000

LinkID           : 23af5850
Transaction      :      01

Segment0         : 020000000000
SegN             : 00
PDU Length       : 0006
FCS              : 64
Message0         : 23af58500100000664020000000000

```

8.7.5.1 PB-ADV Transaction Ack

The new device acknowledges this start transaction.

PBADV Transaction Acknowledge

```

LinkID           : 23af5850
Transaction      :      01
Message          : 23af58500101

```

8.7.6 PB-ADV Provisioning Public Key (Provisioner)

The Provisioner sends its public key to the new device. This message contains the 512-bit public key, and is therefore transmitted using three segments in three messages.

Provisioning Start

```

Public Key       : 2c31a47b5779809ef44cb5eaa5c3e43d5f8faad4a8794cb987e9b03745c78dd
                  919512183898dfbecd52e2408e43871fd021109117bd3ed4eaf8437743715d4f
Message          : 032c31a47b5779809ef44cb5eaa5c3e43d5f8faad4a8794cb987e9b03745c78
                  dd919512183898dfbecd52e2408e43871fd021109117bd3ed4eaf8437743715d
                  4f

```

```

LinkID           : 23af5850
Transaction      :      02

```

```

Segment0         : 032c31a47b5779809ef44cb5eaa5c3e43d5f8fa
Segment1         : ad4a8794cb987e9b03745c78dd919512183898dfbecd52
Segment2         : e2408e43871fd021109117bd3ed4eaf8437743715d4f
SegN             : 02
PDU Length       : 0041
FCS              : d1
Message0         : 23af585002080041d1032c31a47b5779809ef44cb5eaa5c3e43d5f8fa
Message1         : 23af58500206ad4a8794cb987e9b03745c78dd919512183898dfbecd52
Message2         : 23af5850020ae2408e43871fd021109117bd3ed4eaf8437743715d4f

```

8.7.6.1 PB-ADV Transaction Ack

Once the new device receives all the segments of the provisioning public key transaction, it will send the acknowledgment for that transaction.

PBADV Transaction Acknowledge

```

LinkID           : 23af5850
Transaction      :      02
Message          : 23af58500201

```

8.7.7 PB-ADV Provisioning Public Key (Device)

The device sends its public key to the Provisioner. This is again a multi-segment transaction.

Provisioning Start

```

Public Key       : f465e43ff23d3f1b9dc7dfc04da8758184dbc966204796eccf0d6cf5e16500cc
                  0201d048bcbbd899eeefc424164e33c201c2b010ca6b4d43a8a155cad8ecb279

```

8.7.7.1 PB-ADV Transaction Ack

PBADV Transaction Acknowledge

8.7.8 PB-ADV Provisioning Confirmation (Provisioner)

Bluetooth SIG Proprietary

```

k1 SALT          : 5faabe187337c71cc6c973369dcaa79a
k1 P             : 7072636b
k1 T             : ace84c6f002e0b4c23467e75687bae8f
ConfirmationKey  : e31fe046c68ec339c425fc6629f0336f
RandomProvisioner : 8b19ac31d58b124c946209b5db1021b9
AuthValue        : 00000000000000000000000000000000

```

Provisioning Confirmation

```

Confirmation      : b38a114dfdca1fe153bd2c1e0dc46ac2
Message           : 05b38a114dfdca1fe153bd2c1e0dc46ac2
LinkID            : 23af5850
Transaction       : 03

Segment0          : 05b38a114dfdca1fe153bd2c1e0dc46ac2
SegN              : 00
PDU Length        : 0011
FCS               : d1
Message0          : 23af585003000011d105b38a114dfdca1fe153bd2c1e0dc46ac2

```

8.7.8.1 PB-ADV Transaction Ack

The new device will acknowledge the confirmation transaction.

PBADV Transaction Acknowledge

```

LinkID            : 23af5850
Transaction       : 03
Message           : 23af58500301

```

8.7.9 PB-ADV Provisioning Confirmation (Device)

The new device will send its confirmation value using all the information that it has exchanged so far, the authentication value communicated OOB, and a random number that has not been disclosed yet.

```

InvitePDUValue    : 00
CapabilitiesPDUValue : 010001000000000000000000
StartPDUValue     : 0000000000
ProvisionerPublicKey : 2c31a47b5779809ef44cb5eaaf5c3e43d5f8faad4a8794cb987e9b03745c78dd
                    919512183898dfbecd52e2408e43871fd021109117bd3ed4eaf8437743715d4f
DevicePublicKey   : f465e43ff23d3f1b9dc7dfc04da8758184dbc966204796eccf0d6cf5e16500cc
                    0201d048bcbbd899eeefc424164e33c201c2b010ca6b4d43a8a155cad8ecb279
ConfirmationInputs : 0001000100000000000000000000000002c31a47b5779809ef44cb5eaaf5c3e
                    43d5f8faad4a8794cb987e9b03745c78dd919512183898dfbecd52e2408e4387
                    1fd021109117bd3ed4eaf8437743715d4ff465e43ff23d3f1b9dc7dfc04da875
                    8184dbc966204796eccf0d6cf5e16500cc0201d048bcbbd899eeefc424164e33
                    c201c2b010ca6b4d43a8a155cad8ecb279
ConfirmationSalt   : 5faabe187337c71cc6c973369dcaa79a
ECDHSecret         : ab85843a2f6d883f62e5684b38e307335fe6e1945ecd19604105c6f23221eb69

```



```

k1 N      : ab85843a2f6d883f62e5684b38e307335fe6e1945ecd19604105c6f23221eb69
k1 SALT   : 5faabe187337c71cc6c973369dcaa79a
k1 P      : 7072636b
k1 T      : ace84c6f002e0b4c23467e75687bae8f
ConfirmationKey : e31fe046c68ec339c425fc6629f0336f
RandomDevice  : 55a2a2bca04cd32ff6f346bd0a0c1a3a
AuthValue     : 00000000000000000000000000000000

```

Provisioning Confirmation

```

Confirmation : ee521c196b52cc2e37aa40329f554e
Message      : 05ee521c196b52cc2e37aa40329f554e

```

```

LinkID       : 23af5850
Transaction  :      82

```

```

Segment0     : 05ee521c196b52cc2e37aa40329f554e
SegN         : 00
PDU Length   : 0011
FCS          : ec
Message0     : 23af585082000011ec05ee521c196b52cc2e37aa40329f554e

```

8.7.9.1 PB-ADV Transaction Ack

The Provisioner will acknowledge the confirmation transaction from the new device.

PBADV Transaction Acknowledge

```

LinkID       : 23af5850
Transaction  :      82
Message      : 23af58508201

```

8.7.10 PB-ADV Provisioning Random (Provisioner)

The Provisioner will now expose its random number used to generate its confirmation value that it has previously committed to.

Provisioning Random

```

Random       : 8b19ac31d58b124c946209b5db1021b9
Message      : 068b19ac31d58b124c946209b5db1021b9

```

```

LinkID       : 23af5850
Transaction  :      04

```

```

Segment0     : 068b19ac31d58b124c946209b5db1021b9
SegN         : 00
PDU Length   : 0011
FCS          : d3

```

Message0 : 23af585004000011d3068b19ac31d58b124c946209b5db1021b9

8.7.10.1 PB-ADV Transaction Ack

The new device acknowledges this random number transaction.

PBADV Transaction Acknowledge

LinkID : 23af5850
Transaction : 04
Message : 23af58500401

8.7.11 PB-ADV Provisioning Random (Device)

The new device now sends its random number to the Provisioner.

Provisioning Random

Random : 55a2a2bca04cd32ff6f346bd0a0c1a3a
Message : 0655a2a2bca04cd32ff6f346bd0a0c1a3a

LinkID : 23af5850
Transaction : 83

Segment0 : 0655a2a2bca04cd32ff6f346bd0a0c1a3a
SegN : 00
PDU Length : 0011
FCS : 59
Message0 : 23af585083000011590655a2a2bca04cd32ff6f346bd0a0c1a3a

8.7.11.1 PB-ADV Transaction Ack

The Provisioner acknowledges receiving this random number transaction from the new device.

PBADV Transaction Acknowledge

LinkID : 23af5850
Transaction : 83
Message : 23af58508301

8.7.12 PB-ADV Provisioning Data

The Provisioner can now provide the provisioning data required by the new device to become a node in a mesh network. This includes a NetKey along with a network key index, the current IV Index of this network key, and the unicast address of the first element of this node, and therefore all the subsequent addresses of additional elements. This data is encrypted and authenticated using a session key derived from the ECDH shared secret. This data requires two segments to communicate.

ConfirmationSalt : 5faabe187337c71cc6c973369dcaa79a
Random Provisioner : 8b19ac31d58b124c946209b5db1021b9
Random Device : 55a2a2bca04cd32ff6f346bd0a0c1a3a


```

ProvisioningInputs      : 5faabe187337c71cc6c973369dcaa79a8b19ac31d58b124c946209b5db1021b9
                        : 55a2a2bca04cd32ff6f346bd0a0c1a3a
ProvisioningSalt       : a21c7d45f201cf9489a2fb57145015b4
DeviceKey              : 0520adad5e0142aa3e325087b4ec16d8
SessionKey             : c80253af86b33dfa450bbdb2a191fea3
Nonce                 : da7ddbe78b5f62b81d6847487e
NetKey                 : efb2255e6422d330088e09bb015ed707
NetKeyIndex            : 0567
Flags                  : 00
IVIndex                : 01020304
UnicastAddress         : 0b0c
ProvisioningData       : efb2255e6422d330088e09bb015ed707056700010203040b0c
EncProvisioningData    : d0bd7f4a89a2ff6222af59a90a60ad58acfe3123356f5cec29
ProvisioningDataMIC    : 73e0ec50783b10c7

```

Provisioning Data

```

EncProvisioningData    : d0bd7f4a89a2ff6222af59a90a60ad58acfe3123356f5cec29
ProvisioningDataMIC    : 73e0ec50783b10c7
Message                : 07d0bd7f4a89a2ff6222af59a90a60ad58acfe3123356f5cec2973e0ec50783b
                        : 10c7

```

```

LinkID                 : 23af5850
Transaction            : 05

```

```

Segment0               : 07d0bd7f4a89a2ff6222af59a90a60ad58acfe31
Segment1               : 23356f5cec2973e0ec50783b10c7
SegN                   : 01
PDU Length             : 0022
FCS                    : 8b
Message0               : 23af5850050400228b07d0bd7f4a89a2ff6222af59a90a60ad58acfe31
Message1               : 23af5850050623356f5cec2973e0ec50783b10c7

```

8.7.12.1 PB-ADV Transaction Ack

The new device acknowledges the reception of the provisioning data transaction.

PBADV Transaction Acknowledge

```

LinkID                 : 23af5850
Transaction            : 05
Message                : 23af58500501

```

8.7.13 PB-ADV Provisioning Complete

The new device now indicates that it has successfully received and processed the provisioning data.

Provisioning Complete

```

Message           : 08

LinkID            : 23af5850
Transaction       :      84
Segment0         : 08
SegN              : 00
PDU Length       : 0001
FCS               : 3e
Message0         : 23af5850840001003e08

```

8.7.13.1 PB-ADV Transaction Ack

The Provisioner acknowledges receiving the provisioning complete transaction from the new device.

PBADV Transaction Acknowledge

```

LinkID            : 23af5850
Transaction       :      84
Message          : 23af58508401

```

8.7.14 PB-ADV Link Close

Finally, the Provisioner closes the PB-ADV session by using the Link Close message.

Link Close

```

Reason           : 00

```

Provisioning Control

```

LinkID            : 23af5850
Transaction       :      00
Opcode           : 02 (Link Close)
Message          : 23af5850000b00

```

8.8 PB-GATT SAR sample data

The Provisioner is using PB-GATT to transport Provisioning PDU. The ATT_MTU is 23. The Type is Provisioning Public Key (0x03) and the value of the Parameters is:

```

Provisioning PDU Type : 03 (Provisioning Public Key)
Public Key X          : 2c31a47b5779809ef44cb5eaaf5c3e43d5f8faad4a8794cb987e9b03745c78dd
Public Key Y          : 919512183898dfbecd52e2408e43871fd021109117bd3ed4eaf8437743715d4f

```

8.8.1 1st segment

```

ATT Opcode        : 52 (Write Command)
ATT Handle        : 0003
ATT Value         : 43032c31a47b5779809ef44cb5eaaf5c3e43d5f8

```

8.8.2 2nd segment

ATT Opcode : 52 (Write Command)
 ATT Handle : 0003
 ATT Value : 83faad4a8794cb987e9b03745c78dd9195121838

8.8.3 3rd segment

ATT Opcode : 52 (Write Command)
 ATT Handle : 0003
 ATT Value : 8398dfbecd52e2408e43871fd021109117bd3ed4

8.8.4 4th segment

ATT Opcode : 52 (Write Command)
 ATT Handle : 0003
 ATT Value : c3eaf8437743715d4f

8.9 Proxy Configuration Message sample data

The Proxy client is configuring Proxy to use whitelist filtering.

```
CTL : 01
ProxyFilterPkt : 0000

NetKey : d1aafb2a1a3c281cddb0e960edfad852
NID : 10
EncryptionKey : 3a4fe84a6cc2c6a766ea93f1084d4039
PrivacyKey : f695fcce709ccface4d8b7a1e6e39d25
IV Index : 12345678
ProxyNonce : 03000000010001000012345678
IVI NID : 10
CTL TTL : 80
SEQ : 000001
SRC : 0001
DST : 0000
TransportPDU : 0000
NetMIC Size : 64 bits
EncDST || EncTransportPDU : 8b8c2851
NetMIC : 2e792d3711f4b526

Obfuscation

Privacy Plaintext : 0000000000123456788b8c28512e792d
PECB : b86bd60ffbbba6ca41e7109226f247a16
CTL || TTL || SEQ || SRC : 800000010001

ProxyMessage : 10386bd60efbbb8b8c28512e792d3711f4b526

ProxyPDU : 0210386bd60efbbb8b8c28512e792d3711f4b526
```

8.10 Composition Data sample data

This sample represents an example of Composition Data Page 0 (see Section 4.2.1). The data below is a sequence of octets.

```
0C001A0001000800030000010501000000800100001003103F002A00
```

To help with parsing of this sequence of octets, it has been formatted with appropriate spacing characters.

```
0C00 1A00 0100 0800 0300 0001 05 01 0000 0080 0100 0010 0310 3F002A00
```

Note: The composition data is little-endian.

The above Composition Data Page 0 can be described as follows:

- CID is 0x000C
- PID is 0x001A
- VID is 0x0001
- CRPL is 0x0008
- Features is 0x0003 – Relay and Friend features.
- Loc is “front” – 0x0100
- NumS is 5
- NumV is 1
- The Bluetooth SIG Models supported are:
 - 0x0000, 0x8000, 0x0001, 0x1000, 0x1003
- The Vendor Models supported are:
 - Company Identifier 0x003F and Model Identifier 0x002A



9 References

- [1] Bluetooth Core Specification, Version 4.0 or later
- [2] Bluetooth Core Specification, Version 5.0 or later
- [3] Bluetooth Core Specification Addendum 6
- [4] Bluetooth SIG Assigned Numbers (<http://www.bluetooth.com/specifications/assigned-numbers>)
- [5] GATT Bluetooth Namespace Descriptors (<https://www.bluetooth.com/specifications/assigned-numbers/gatt-namespace-descriptors>)
- [6] Bluetooth SIG Company Identifiers (<https://www.bluetooth.com/specifications/assigned-numbers/company-identifiers>)
- [7] Core Specification Supplement (CSS) v6 or later
- [8] RFC4122 – A Universally Unique Identifier (UUID) URN Namespace (<https://tools.ietf.org/html/rfc4122>)
- [9] RFC4493 – The AES-CMAC Algorithm (<https://tools.ietf.org/html/rfc4493>)
- [10] RFC3610 – Counter with CBC-MAC (CCM) (<https://tools.ietf.org/html/rfc3610>)
- [11] Bluetooth Mesh Model specification
- [12] FIPS PUB 186-4 (<http://dx.doi.org/10.6028/NIST.FIPS.186-4>)
- [13] NIST Special Publication 800-56A, Revision 3 (<http://dx.doi.org/10.6028/NIST.SP.800-56Ar3>)

