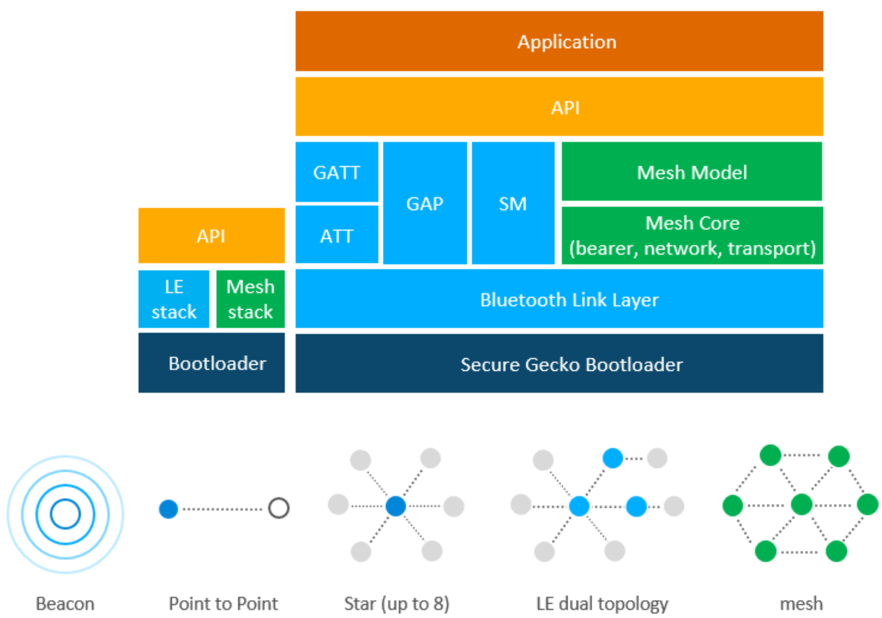
AN1098: Understanding the Silicon Labs Bluetooth Mesh Lighting Demonstration

The Bluetooth mesh SDK comes with an example project that creates an wireless network of lights and a switches using Bluetooth mesh technology. The example assumes usage of Silicon Labs WSTKs for switches and lights and an Android mobile phone for provisioning and controlling the network. In this document we discuss the basics of Bluetooth mesh required to understand the example, and walk through key aspects of the application source code.

This document assumes you have read *QSG148: Getting Started with the Silicon Labs Bluetooth Mesh Demonstration Software,* installed the Bluetooth mesh SDK, and successfully run the example.

KEY FEATURES

- Short introduction to Bluetooth mesh
- Lighting example application description and code walkthrough
- Silicon Labs Bluetooth mesh mobile application



Bluetooth LE and mesh stacks and supported topologies

1 Introduction

This document focuses on explaining the Bluetooth mesh lighting demo, installed as part of the Bluetooth mesh SDK. For the most part the documentation centers on the example application and its usage flow, explaining key parts of the source code and the Silicon Labs Bluetooth Mesh Android application, but also includes a brief discussion of some concepts of the specification important for understanding the example.

In the following subsections, we briefly walkthrough the relevant aspects of the Bluetooth mesh technology. Chapter 2 describes the features and functions of the Lighting Demonstration, and Chapter 3 focuses on the mobile application.

1.1 Bluetooth Mesh

Bluetooth mesh is a new topology available for Bluetooth LE devices and applications. Previously Bluetooth devices have been using point-to-point connectivity or broadcasting topologies to communicate with other devices. Bluetooth mesh extends that and allows both many-to-many device communications and using Bluetooth devices in a mesh topology. This enables multi-hop communications between Bluetooth devices and much larger-scale Bluetooth device networks than have been possible previously.

Bluetooth mesh uses Bluetooth LE advertising channels to send and receive messages between the Bluetooth mesh nodes, but it can also use Bluetooth connections and GATT services to connect non-Bluetooth mesh-capable devices such as smartphones or tablets to the Bluetooth mesh network.

Bluetooth mesh also uses its own security architecture, which is separate from the normal Bluetooth LE security architecture, although the same AES-CCM 128-bit and Elliptic Curve Diffie Hellman (ECDH) security algorithms are used.

Bluetooth mesh also defines its own application layer called mesh model which is different than the GATT-based profiles and services non-mesh Bluetooth LE devices use. The new application layer was defined to address the requirements and needs of mesh-based topologies and also to make Bluetooth mesh a full stack solution and enable interoperable mesh devices to be built.

1.1.1 Bluetooth Mesh Network Roles and Node Features

The Bluetooth mesh network typically consists of multiple nodes. All nodes can transmit and receive mesh messages, but they can optionally also support one or more additional features. If a node does not implement any of the additional features it is considered as an edge node. Various node types are illustrated in the following figure.

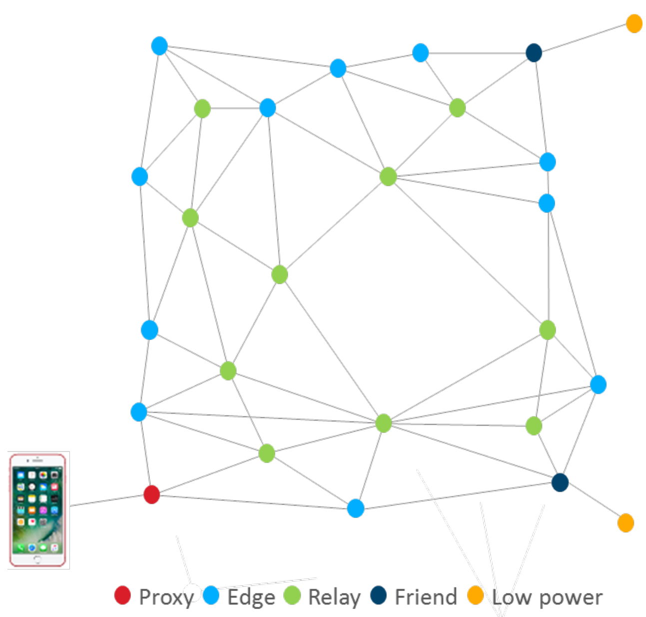


Figure 1-1. Node Types

The four types of specified node features are as follows:

Proxy feature: Enables message proxy between Bluetooth mesh and GATT and enables devices such as smartphones to connect to Bluetooth mesh.

Relay feature: Relays messages to extend the range and scale of a Bluetooth mesh network.

Friend feature: Implements an additional message cache to support nodes with the low power feature.

Low power feature: Allows sleeping and polling of messages from friend nodes at known time intervals.

Relay feature, Friend feature, and Low power feature are out of scope of the lighting demonstration and this document. For further information on these features and Bluetooth mesh technology, please go to the Silicon Labs Bluetooth mesh learning center.

1.1.2 Provisioning

Provisioning refers to the operation where devices that are not part of any Bluetooth mesh network are transformed into nodes that are part of one or more Bluetooth mesh networks. Provisioning happens for example when a new light bulb is installed and taken into use so it can be controlled by switches or dimmers.

Provisioning is mainly a security process where the first level security keys are generated by the provisioner and transferred to the device that is being provisioned to make it part of a Bluetooth mesh network.

The provisioning process begins when a device starts to send un-provisioned Bluetooth beacon packets and the provisioner receives them. The provisioner then initiates the provisioning process, the devices exchange public keys and both generate session keys. The session keys are used to secure the session, in the transfer of the actual network key, and the rest of the provisioning process. After provisioning, each device, now a node in the network, has the network key, a security parameter called the IV index, and its unicast address.

1.1.3 Publish and Subscribe

In Bluetooth mesh, communication to a group of devices is typically implemented through publish and subscribe mechanism. This is an easy-to-understand concept which also simplifies the setup of Bluetooth mesh networks and adding and reconfiguring nodes.

Usually the Bluetooth mesh nodes are configured into groups, which may represent their physical location (kitchen or living room) or particular function (lights or window coverings). Usually the devices are also controlled as groups, so the same message is sent to all devices in a group. To accomplish this functionality Bluetooth mesh uses a concept called publish – subscribe, where nodes such as lights subscribe to messages groups and nodes like switches publish messages to those groups. At the network layer each group is assigned a group address and multicast messaging is used to send the messages to all devices in a particular group.

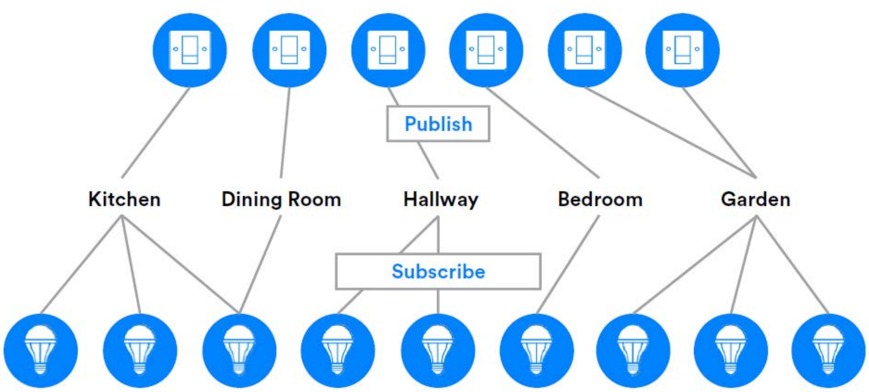


Figure 1-2: Publish and Subscribe

The benefit of publish and subscribe is that when a new node is added or an existing node is removed or replaced only that node needs to be provisioned and configured.

2 Bluetooth Mesh Lighting Demonstration

2.1 Requirements

- Simplicity Studio
  - Bluetooth Mesh SDK 1.2.0 or later, distributed through Simplicity Studio
  - The pre-built demo binaries and source code are included in the SDK.
  - Simplicity Studio has a network analyzer capable of capturing and decoding Bluetooth mesh packets.
  - The actual code development can be done with Simplicity Studio, IAR EWARM, or command line tools
- Silicon Labs Bluetooth mesh Android application
  - Used for discovering and provisioning devices over GATT.
  - Includes network, group and publish-subscribe setup.
  - Allows device configuration and control.
  - Requires Android 6 (API23) or later.
- For the full experience at least 3 pcs of Silicon Labs Blue Gecko SoC Wireless Starter Kits are needed.
  - 2 kits are used as lights with proxy feature.
  - 1 kit is used as a switch.
  - EFR32BG12, EFR32MG12, EFR32BG13, and EFR32MG13 SoCs as well as the BGM13 module support Bluetooth mesh software.

See *QSG148: Getting Started with the Silicon Labs Bluetooth Mesh Lighting Demonstration* for more information on obtaining required hardware and software, and running the demonstration

The demonstration setup can, in principle, consist of any number of switch nodes and light nodes. A single switch node can control an arbitrary number of light nodes by sending commands to a group address. Similarly, a light node can receive on/off commands from multiple switches.

2.2 Mesh Network Implementation

The demonstration implementation process can be divided into four main phases, as follows:

1. Un-provisioned mode – After the demo firmware is installed, the device starts in un-provisioned mode.
2. Provisioning–The devices are provisioned to a Bluetooth mesh network and network security is set up.
3. Configuration -The group, publish and subscribe, and application security are configured.
4. Normal operation – The light node(s) can be controlled by the switch(es) and also from the smartphone application

In the first phase, all the devices are un-provisioned and transmitting un-provisioned beacons. They do not have any network keys or application keys configured and publish and subscribe settings are not set. In this state the nodes are simply waiting for the provisioner to assign them into a Bluetooth mesh network and configure publish and subscribe and mesh models. In this state the devices can be detected by the smartphone application.

In the provisioning phase the provisioner adds lights and switches to a Bluetooth mesh network. A network key is generated and distributed to the nodes and each node is assigned a unicast address.

In the configuration phase the provisioner configures: groups, publish and subscribe, application-level security, and mesh models.

After provisioning and configuration the Bluetooth mesh network is operational and switches can be used to control the lights. The WSTK switch's buttons can be used to control all the lights in a group. The same functionality can be done with the smartphone application, but it can also control individual lights using unicast addressing.

2.3 Code Walkthrough

The Bluetooth mesh SDK includes separate example projects for the switch and for the light. These are named **BT Mesh – Light Example** and **BT Mesh – Switch Example**. Both examples are implemented using the same event-driven architecture that is used in plain Bluetooth (non-mesh) applications.

For information about Bluetooth C application development please see *UG136: Silicon Labs Bluetooth® C Application Developer's Guide*.

2.3.1 Un-provisioned Mode, Provisioning, and Configuration

In un-provisioned mode, both examples behave the same way. The un-provisioned device simply starts sending un-provisioned beacons and waits for a provisioner to provision and configure it.

After receiving the `system_boot` event (`gecko_evt_system_boot_id`), the application calls the function `gecko_cmd_mesh_node_init()` to initialize the Bluetooth mesh node stack.

The event `gecko_evt_mesh_node_initialized_id` indicates that the Bluetooth mesh node stack initialization is complete. This event also includes information about the node status. The application first checks the provisioning status. If the node is not provisioned (the default state when the device is first powered up after programming) then the application starts un-provisioned beaconing by calling `gecko_cmd_mesh_node_start_unprov_beaconing()`.

The API call `gecko_cmd_mesh_node_start_unprov_beaconing` takes one parameter (`bearer`) that selects which bearers are used (PB-ADV, PB-GATT, or both). In this example, both bearers are used. Because the PB-GATT bearer is enabled, the device will begin advertising its provisioning GATT service. This allows the smartphone application to detect un-provisioned nodes.

When un-provisioned beaconing has been started the application waits for the provisioner (in this case, the smartphone app) to start provisioning. Start of provisioning is indicated with the event `mesh_node_provisioning_started`.

During provisioning, no actions are required from the user application. The configuration of network keys and other operations are handled automatically by the Bluetooth mesh stack. Both the light and the switch application simply start blinking the two LEDs on the WSTK to indicate that provisioning is in progress. Then they wait for the event `gecko_evt_mesh_node_provisioned_id` that indicates provisioning is complete.

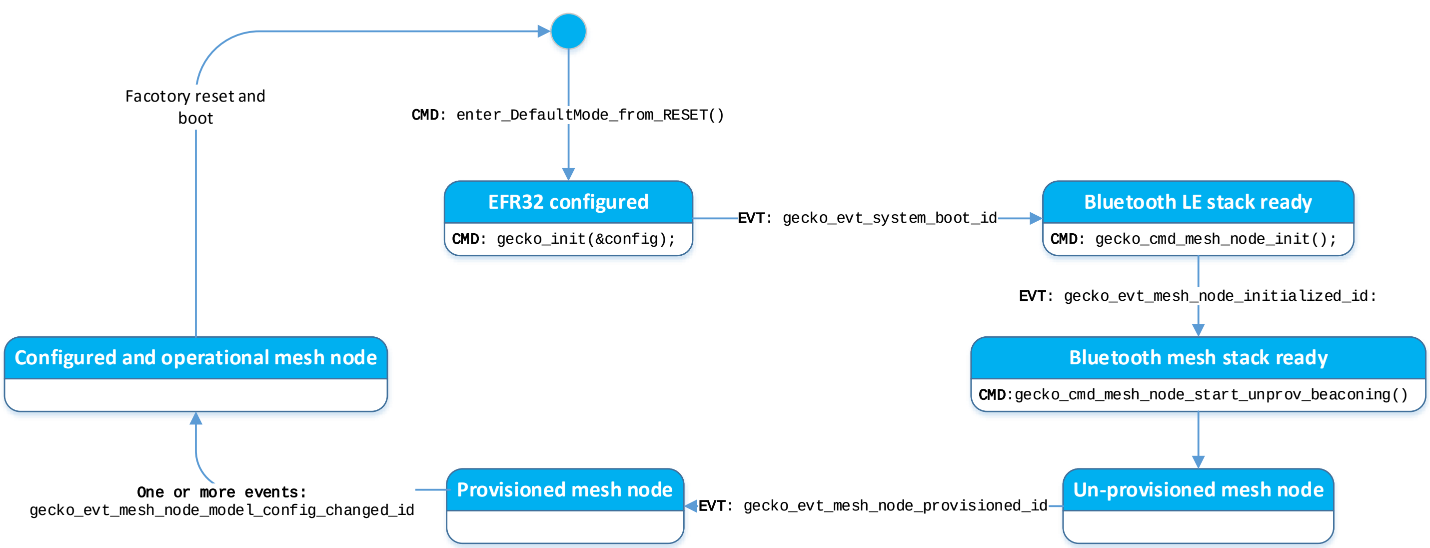


Figure 2-1: Life Cycle of the Application

The next step after provisioning is configuration of the node. As explained in *QSG148: Getting Started with the Silicon Labs Bluetooth Mesh Lighting Demonstration*, the smartphone app is used to configure a node either as a switch or a light and the node is assigned to a group. The configuration procedure consists of following steps:

- Provisioner distributes an application key to the node.
- Application key is bound to the Bluetooth mesh generic on/off model.
- Publish address and settings are configured.
- Subscribe address and settings are configured.

The configuration phase is mostly handled between the Mesh stack and the provisioner and it does not require any involvement from the user application in the node. The following events are generated by the stack to give status information about the ongoing configuration:

- `gecko_evt_mesh_node_key_added_id:` generated when the provisioner has sent a new key (network or application)
- `gecko_evt_mesh_node_model_config_changed_id:` indicates that the provisioner has modified configuration of the local model (either publish or subscribe settings changed)

The node application includes some debug prints to keep track of the configuration process but no action is needed in the application code when either of these events is raised.

Up to this point, the code in the examples **BT Mesh – Light Example** and **BT Mesh – Switch Example** is almost identical.

2.3.2 Switch Node Example

This section describes basic operation of the **BT Mesh – Switch Example.** It is assumed that the node is already provisioned and publish - subscribe settings have been configured by the smartphone app. The switch node has one simple task: listen to push button presses and control the brightness, color temperature,and on/off state of the lights in the group. Short button presses (less than 250 ms) are used to adjust light brightness up (PB1) and down (PB0). Long button presses (more than 250 ms and less than 1 s) are used to adjust light color temperature up (PB1) and down (PB0). A very long press (more than 1 s) turns the light on (PB1) or off (PB0).

The on/off control uses the **Generic OnOff** model, the brightness control uses the **Light Lightness** model, and the color temperature control uses **Light CTL** model.

Upon receiving the `gecko_evt_mesh_node_initialized_id` event, the node application enables GPIO interrupts for development kit buttons PB0 and PB1. The interrupt handler code measures the duration of the button press to distinguish short, long, and very long presses. If the button is held down 1000 ms or longer the application detects it as a very long press.

Handling of very long button presses is implemented in function `handle_very_long_press()`. For each very long button press, the application publishes three consecutive on/off requests to the group address that has been set by the smartphone app. The request is sent multiple times for increased reliability. Note that it is the application's responsibility to choose a suitable strategy for reliable communications. In this example, multiple application message transmissions were chosen.

Sending a single on/off request is implemented in function `send_onoff_request()`. A soft timer is used to trigger three calls to `send_onoff_request()` with a 50 ms delay between each call.

The mesh stack API call used to send one on/off transaction is `gecko_cmd_mesh_generic_client_publish()`. This is a common API call that is used to publish data for several client models. It is not limited to the generic on/off client only. For example, publishing data as a generic transition time client would be done using the same API call. The first parameter `model_id` selects which model is being used.

In addition to the desired on/off status, the publish API call has some additional parameters such as **transaction identifier**, **transition time** and **delay**.

Transaction identifier is a running number that is incremented for each transaction. In this example, each button press triggers three consecutive on/off requests. The transaction identifier is same for each of these requests so that, at the receiving end, duplicate requests can be filtered out. In other words, all the three published messages are part of the same transaction and they will trigger only one event at the receiving light node.

The delay parameter can be used to indicate that the on/off transition should not be executed immediately but after a given delay. In this example, the delay parameter is set to values of 100 ms / 50 ms / 0 in the first, second and third request, respectively. The purpose is to ensure that all lights in the target group change their state simultaneously, regardless of which of the three on/off requests was captured on the receiving side.

Handling of short button presses is implemented in function `handle_button_press()`. Short presses are used to adjust light brightness up and down. The application sends a request using the **Light Lightness** model. The last level that has been set is stored in a variable (type uint16) and the level is adjusted up or down each time a short button press is detected.

Sending a single light lightness request is implemented in function `send_ligthness_request(),` which is very similar to `send_onoff_request()` that is used for on/off requests. Both of these use the same API call `gecko_cmd_mesh_generic_client_publish()` to publish the request. The difference is in the model ID that is passed as argument and the parameter data type.

Handling of long button presses is implemented in function `handle_long_press()`. Long presses are used to adjust light color temperature up and down. The application sends a request using the **Light CTL** model. The last temperature that has been set is stored in a variable (type uint16) and the temperature is adjusted up or down each time a long button press is detected.

Sending a single light CTL request is implemented in function `send_ctl_request()`, which is very similar to `send_lightness_request()` that is used for light brightness requests. Both of these use the same API call `gecko_cmd_mesh_generic_client_publish()` to publish the request. The difference is in the model ID that is passed as argument and the parameter data type.

The application code that implements the light switch functionality is relatively simple because many aspects are automatically handled by the mesh stack. For example, the switch does not need to know anything about the light nodes that it is controlling. Any number of light nodes can be subscribed to the on/off requests that are published by the switch node.

The switch node does not need to know the group address that has been configured by the provisioning application. It simply publishes the on/off requests using the `gecko_cmd_mesh_generic_client_publish()` API call and the stack automatically sends the requests using the group address that has been configured by the provisioner.

2.3.3 Light Node Example

This section describes basic operation of the **BT Mesh – Light Example.** It is assumed that the node is already provisioned and publish and subscribe settings have been configured by the smartphone app.

The main feature in the light node is that the development kit LEDs are turned on or off based on the requests that are received from switch nodes or from the smartphone application. The brightness of the LEDs can also be controlled. On/off control is based on the Bluetooth mesh Generic OnOff model and the brightness control is based on the Light Lightness model. The Light CTL model supports color temperature requests. Color temperature changes are shown on the WSTK LCD display.

The light node supports following states:

- Generic OnOff
- Generic Level
- Generic OnPowerUp
- Generic Default Transition Time
- Light Lightness
- Light CTL

The OnPowerUp state enables configuration of the default state after power is applied to the light node. The possible settings are listed below.

OnPowerUp Setting	Description (light node)
OFF	Light is off after power up
ON	Light is on after power up
RESTORE	The state before light was powered down is restored at next power up

The transition time model makes it possible to configure how long it takes for the light to transition from one state to another.

To support all the states listed above, the light node must store its internal state permanently so that it is preserved over reboots and power cycles. The state information is kept in a struct named `lightbulb_state`. This struct contains the following fields.

Struct member name	Description
onoff_current	Current state of light (ON or OFF)
onoff_target	Target state of light (ON or OFF)
transtime	Default transition time
onpowerup	Light state after power up (possible values OFF/ON/RESTORE)
lightness_current	Current brightness (possible values from 0 to 65535)
lightness_target	Target brightness
lightness_last	Last non-zero brightness
lightness_default	Default brightness
pri_level_current	Current generic level on primary element (possible values from -32768 to 32767)
pri_level_target	Target generic level on primary element

Struct member name	Description
temperature_current	Current color temperature (possible values from 800 to 20000)
temperature_target	Target color temperature
temperature_default	Default color temperature
temperature_min	Minimum color temperature
temperature_max	Maximum color temperature
deltauv_current	Current value of delta UV (possible values from -32768 to 32767)
deltauv_target	Target value of delta UV
deltauv_default	Default value of delta UV
sec_level_current	Current generic level on secondary element (possible values from -32768 to 32767)
sec_level_target	Target generic level on secondary element

The light state initialization is implemented in function `lightbulb_state_init()`. This function initializes the mesh library by calling `mesh_lib_init()`. The mesh library is an adaptation layer between the mesh stack and the application code that enables using multiple models with a small set of generic API calls.

The light node registers callback functions for each of the models that it supports. This is done in function `init_models()` as shown for three models in the following image.

```
static void init_models(void)
{
  mesh_lib_generic_server_register_handler(MESH_GENERIC_ON_OFF_SERVER_MODEL_ID,
                                           0,
                                           onoff_request,
                                           onoff_change);
  mesh_lib_generic_server_register_handler(MESH_GENERIC_POWER_ON_OFF_SETUP_SERVER_MODEL_ID,
                                           0,
                                           power_onoff_request,
                                           power_onoff_change);
  mesh_lib_generic_server_register_handler(MESH_GENERIC_TRANSITION_TIME_SERVER_MODEL_ID,
                                           0,
                                           transtime_request,
                                           transtime_change);
}
```

The first parameter passed to function `mesh_lib_generic_server_register_handler()` is the model ID. The light node registers handlers for eight different models:

- Generic OnOff Server
- Generic PowerOnOff Server
- Generic Default Transition Time Server
- Light Lightness Server
- Generic Level Server
- Light CTL Server
- Light CTL Setup Server
- Light CTL Temperature Server

On the server side, the mesh library works as follows. When any generic request from a client is received the event `gecko_evt_mesh_generic_server_client_request_id` is raised. The application then calls function `mesh_lib_generic_server_event_handler` from the mesh library and passes the event as parameter. The mesh library decodes the model ID from the event and invokes the callback function that has been registered for that model.

For example, in the light node any Generic OnOff request will invoke the callback function `onoff_request()`

The `onoff_request()` function is called whenever an on/off request is received either from one of the switch nodes or from the smartphone app. This is the piece of code in the light node that turns lights on and off.

If the request does not specify any transition time or delay then the light state is changed immediately. Alternatively, the client may have requested a delay and/or a transition time, meaning that the transition does not happen instantly. In such case, the light node application starts a soft timer with the given delay. The light state is not changed until the soft timer expires.

Light Lightness requests are handled in function `lightness_request()`. The lightness request includes a parameter of type uint16 that indicates the light brightness on a scale of 0..65535. The example code uses pulse-width modulation (PWM) to drive the LEDs. The PWM is implemented using a 16-bit timer and the requested brightness value is directly mapped to the value of the Compare/Capture register of the timer. For example, value 32768 will result in 32768/65536 ~ 50% brightness / PWM duty cycle. The duty cycle of the PWM signal is displayed on the LCD so that it is easy to compare the brightness that has been requested and the brightness that is currently set in the light node.

The Generic OnOff state is bound with the Light Lightness state. This means that, if we turn off the light using an on/off request, the last value of brightness is saved by the application and is recovered after the application receives an on/off request that turns on the light. If brightness is set to 0 using lightness request, the generic on/off state is set to OFF. If brightness is set to a positive value, the generic on/off state is set to ON.

Brightness could be also changed using Generic Level requests handled in function `pri_level_request()`. The generic level request includes a parameter of type int16 that indicates brightness level. The conversion from level to lightness is made by adding 32768 to the level value.

Light CLT requests are handled in function `ctl_request()`. The ctl request includes three parameters that indicate the light brightness, color temperature, and delta UV. The first two parameters are of type uint16, and the third is of type int16. Actual color temperature and deltaUV are displayed on WSTK LCD below the lightness. Color temperature is limited by spec to scale 800..20000 K. Limits could be changed by `ctl_setup_request()` with type of request set to *ctl_temperature_range*. Also the default values for ctl state could be changed using `ctl_setup_request()` with type of request set to *ctl_default* .

3 Network Analyzer

Network Analyzer is a packet capture, decoder software and visualization application and is part of Silicon Labs Simplicity Studio. Network Analyzer has support for Bluetooth LE and Bluetooth mesh packet capture and the latest version of Simplicity Studio also has decoders to decode the Bluetooth LE and mesh traffic.

The EFR32 SoCs have a dedicated Packet Trace Interface (PTI), which outputs all the radio traffic sent and received by a particular EFR32 device, and Network Analyzer is able to capture this traffic. On the EFR32 the PTI functionality can be enabled or disabled at the source code level so it can be enabled during development, but can then be disabled for production software.

Silicon Labs Wireless Starter Kits (WSTKs) support PTI packet capture either over USB, which is useful for capturing packets from a few WSTKs at a time, or over an Ethernet connection. The Ethernet connection also provides access to PTI, and this functionality enables building and debugging a network of WSTKs and large scale testing environments for Bluetooth mesh.

The easiest way to start a Network Analyzer session for a specific application is to use ***Profile -> Profile AS -> Network Analyzer Target***

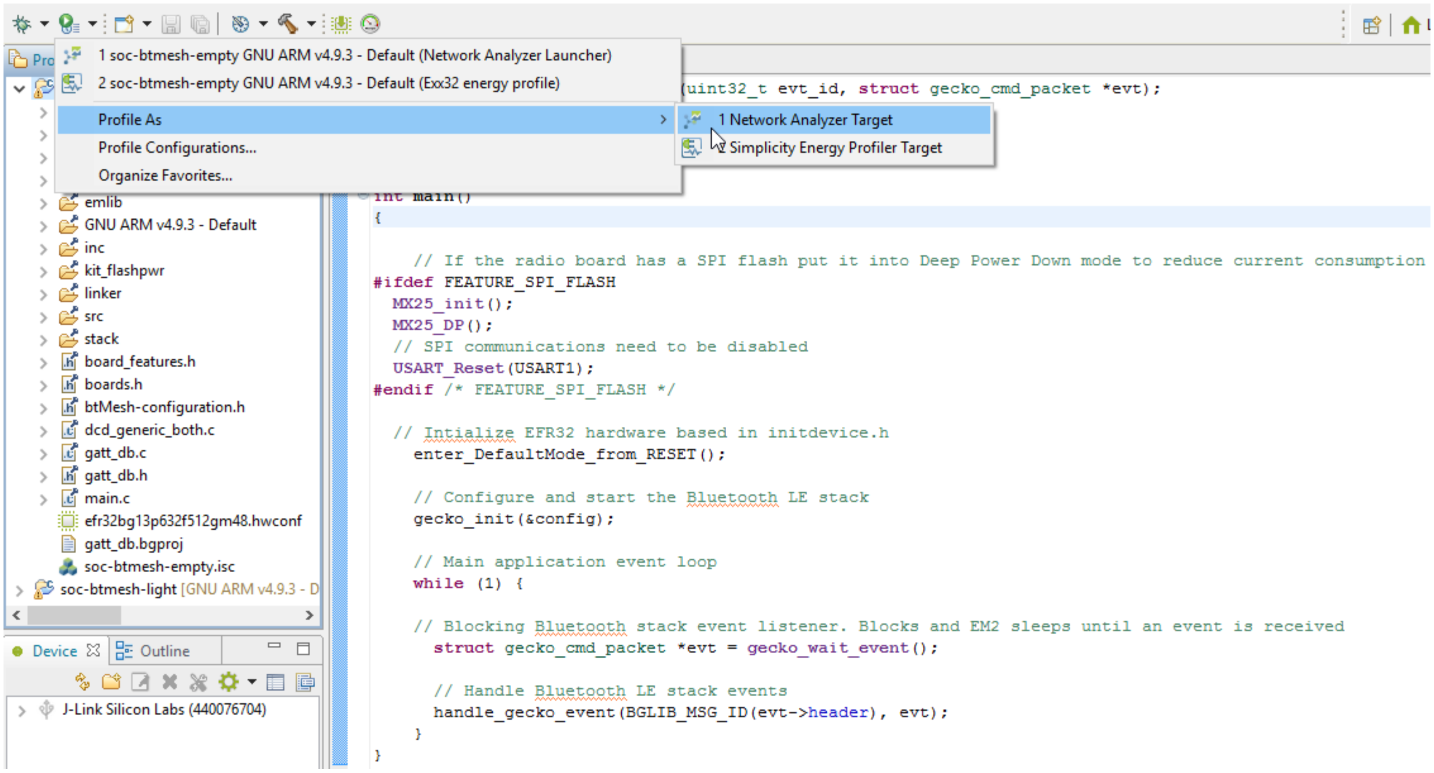


Figure 3-1: Starting Silicon Labs Network Analyzer

4 Bluetooth Mesh Stack and Application for Smartphones

Silicon Labs also provides a Bluetooth mesh stack and a reference application for smartphones. The application can be used to provision mesh-capable Bluetooth devices as nodes that are part of a Bluetooth mesh network, as well configure the nodes, set up groups, and the publish subscribe settings for nodes. At the time of writing this document the application supports one physical network, multiple groups and Lighting mesh models, but the application will be constantly updated for new features and functionality. Also at the time of writing this document only an Android version is available, but an iOS version will be made as well. Contact your local Silicon Labs sales office for more information.

As the smartphones at the time of writing this document do not natively support Bluetooth mesh, Silicon Labs also provides the Bluetooth mesh stack for the phones. The mesh stack is needed for the phone to be able to provision, configure, and control the Bluetooth mesh nodes over the GATT bearer. The figure below illustrates the architecture and the relationship between the Bluetooth stack on the phone operating system and the Silicon Labs Bluetooth mesh stack, as well how the application relates to this.

The Bluetooth mesh stack will be available as a binary library for phone application developers. A reference application implementing the Bluetooth mesh stack, provisioning, configuration, and device control is available in the Google Play and Apple App Stores. Currently only the Android application is available.

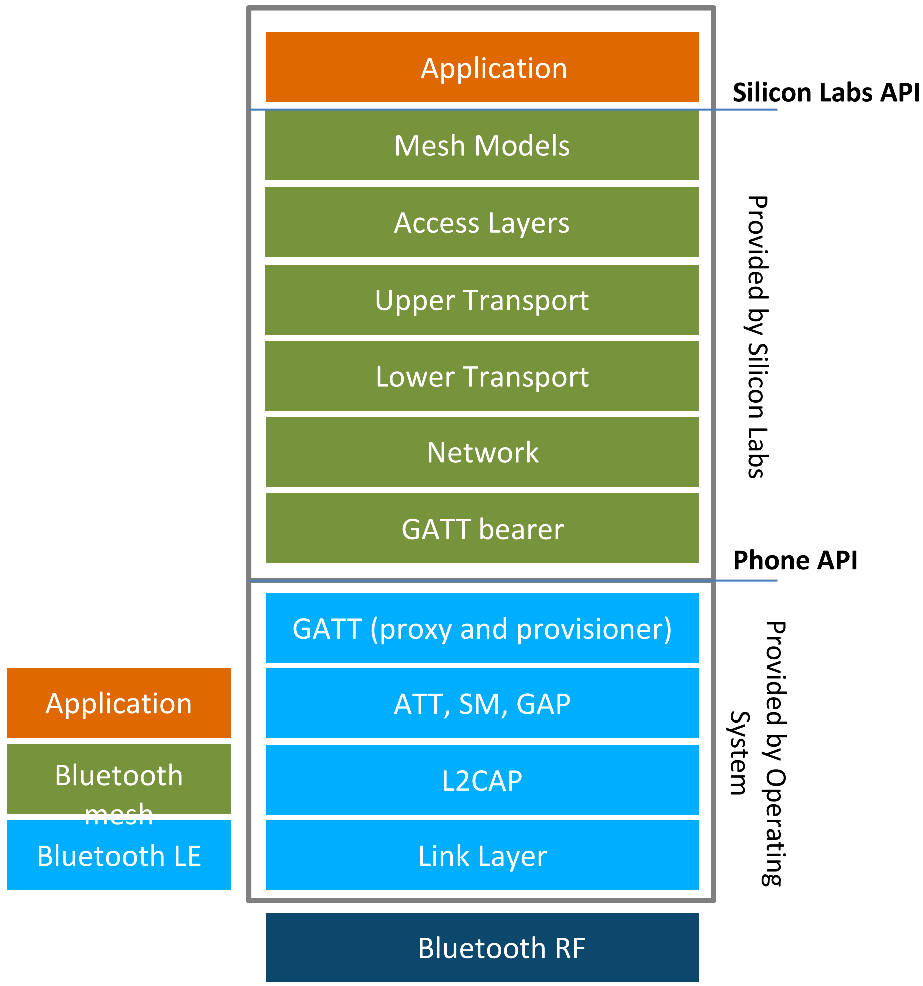
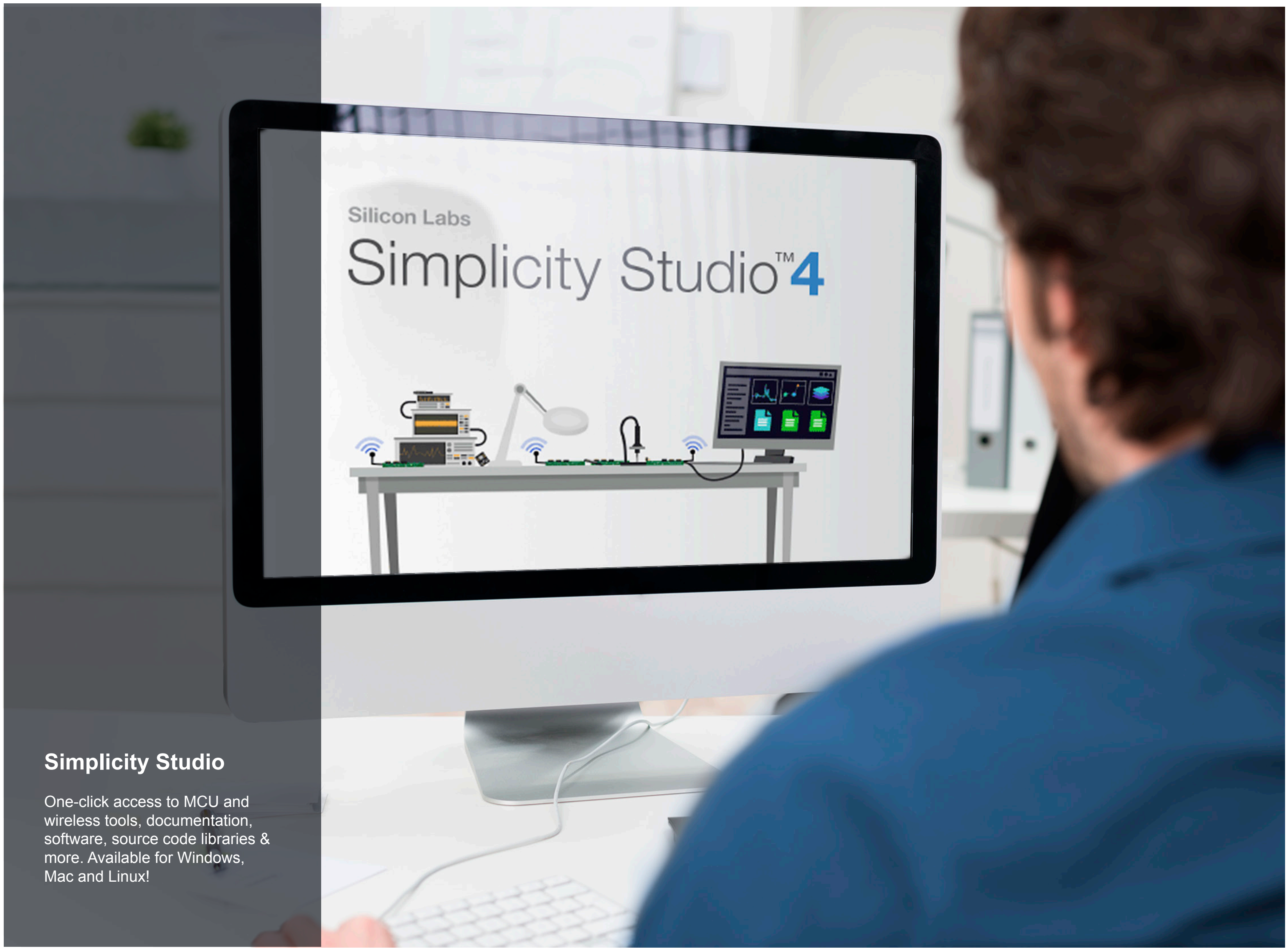


Figure 4-1: Bluetooth Stacks and Application Architecture on Smartphones



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