



## Instruction

### Z-Wave Plus V2 Application Framework SDK7

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## 1 Definitions, acronyms and abbreviations

Abbreviation	Explanation
AGI	Association Group Information
AL	Always Listening
APL	Application Layer
CC	Command Class
DLPDU	Data Link Protocol Data Unit
FL	Frequently Listening
ISM	(unlicensed) Industrial Scientific and Medical
ISR	Interrupt Service Routine
MAC	Medium Access Control
MPDU	MAC Protocol Data Unit
NIB	Network Information Base
NIF	Node Information Frame Command. Refer to [22]
NLDE	Network Layer Data Entity
NL	Non-Listening
NPDU	Network Layer Protocol Data Unit
NLME	Network Layer Management Entity
NSDU	Network Service Data Unit
NWE	Network Wide Exclusion
NWI	Network Wide Inclusion
NWK	Network Layer
NLDE-SAP	Network Layer Data Entity - Service Access Point
NLME-SAP	Network Layer Management Entity - Service Access Point
MLDE-SAP	MAC Layer Data Entity - Service Access Point
MLME-SAP	MAC Layer Management Entity - Service Access Point
OSI	Open System Interconnection
OTA	Over The Air
PLDE-SAP	Physical Layer Data Entity – Service Access Point
PLME-SAP	Physical Layer Management Entity – Service Access Point
PHY	Physical layer
S0	Security 0 Command Class
S2	Security 2 Command Class. Refer to [13]
S2 DSK	Security 2 Device Specific Key. Refer to [13]
SAP	Service Access Point
SAR	Segmentation and Reassembly
SDK	Software Development Kit
SIS	SUC ID Server
SUC	Static Update Controller
ZAF	The Z-Wave Plus Application Framework

## 2 Introduction

This document describes the Z-Wave Plus V2 Application Framework (ZAF) version 10.1x.x distributed on Z-Wave 700 SDK 7.1x.x.

## 3 Purpose

The purpose of the ZAF is to facilitate the implementation of robust Z-Wave Plus V2 compliant products in a fast and cost-effective manner. The ZAF include device types and command classes for interoperable deployments. Interoperability is ensured between all device types thanks to the Z-Wave certification program. The Z-Wave Alliance manages the Z-Wave certification program, but certification testing is performed by independent test houses. Certification ensures that a product correctly implements all device and command classes that it claims to support. The Z-Wave logo is only granted to products passing certification.

## 4 Introduction to the Z-Wave Overview

The Z-Wave protocol is a low bandwidth half duplex protocol designed for reliable wireless communication in a low-cost control network. The main purpose of the protocol is to enable short message transportation in a reliable manner. The Z-Wave protocol is not designed to transfer a large amount of data or any kind of streaming or timing critical data.

### 4.1 The Z-Wave Protocol Stack Architecture

The Open System Interconnection (OSI) reference model is a representation system for characterizing and standardizing the functions of a communication system in terms of abstraction layers. This allows us to describe similar communication functionalities into logical layers. The 7 layers of the OSI model are regarded by many as an idealized model; too abstract and fine-grained for most real-world protocols. It is however useful to refer to the OSI model when describing a given communication protocol framework. With respect to that, the Z-Wave protocol stack would be described using the model as shown in Figure 1. Note that the Z-Wave application layer consists of the OSI stack layers known as transport, session, presentation and application.

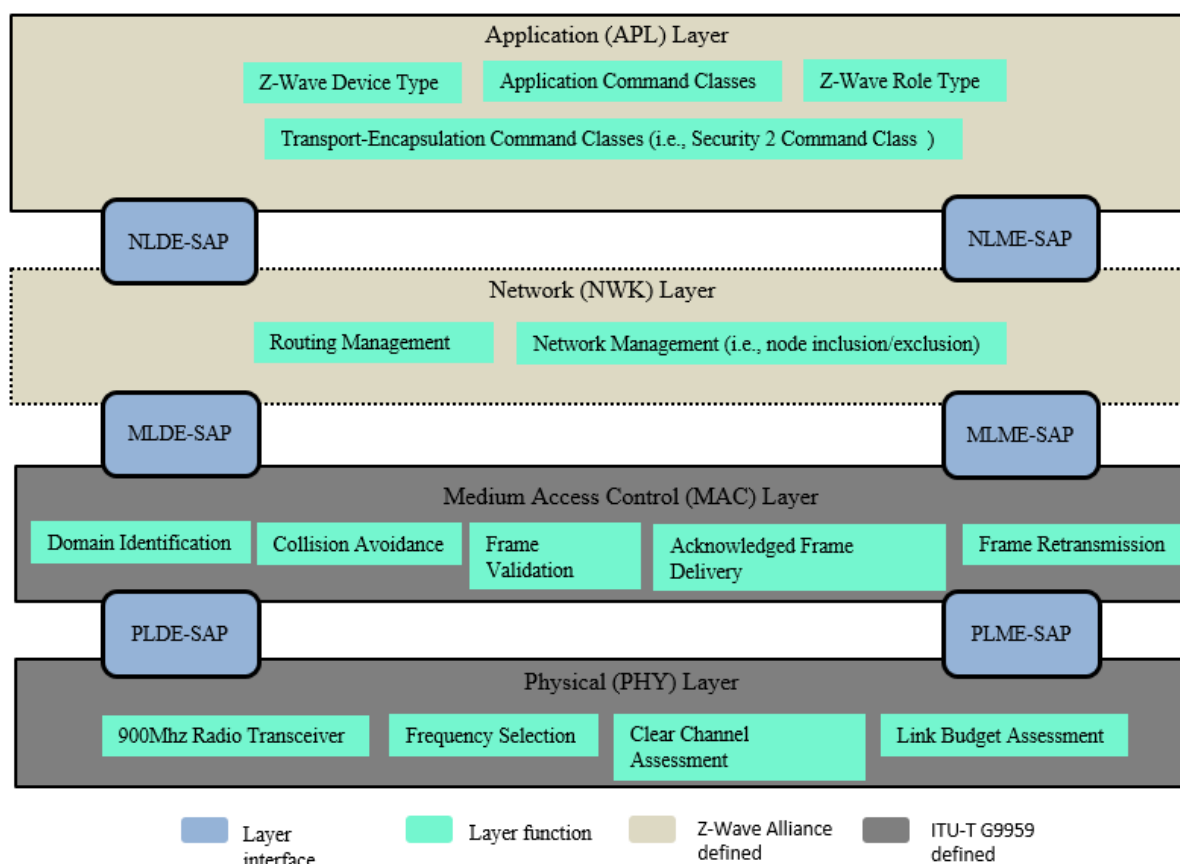


Figure 1. Z Wave Protocol Stack Architecture



As depicted in Figure 1, the Z-Wave protocol stack is made up of OSI layers where each layer performs set of services for the upper layer. Each layer has two main interfaces to facilitate the communication with upper layers through a Service Access Point (SAP). The interfaces are described as a data entity and management entity that provide a data transmission service and all other services, respectively.

ITU-T G.9959 [25] defines the physical and medium access control layers.

- The physical layer offers a data flow control between the MAC and PHY layers and adds PHY-related management headers. The PHY layer is responsible for activation and deactivation of the radio transceiver, data transmission and reception, frequency selection, clear channel assessments, and the link budget assessment of received frames.
- The MAC layer defines the Z-Wave data transfer model and frame structure. During a Z-Wave frame transmission, the MAC layer takes the payload data from higher layers and constructs the MAC data payload (MPDU) and the MPDU header. The header comprises addresses, frame control and frame length information. The frame control field is about 16 bits in length and contains information about the frame type and other control flags that can be used by higher layer.

On the foundation of those two lower layers, the Z-Wave alliance defines the Network layer (NWK) and application layers.

The Z-Wave Network Layer (NWK) defines a multi-hop routing protocol, that is employed by Z-Wave nodes to extend their communication range. It means that the Z-Wave nodes can therefore send frames to nodes that are not in direct radio communication range. Besides, the Z-Wave NWK layer is responsible for network formation (i.e., inclusion/exclusion of nodes to/from a network) and its maintenance. The Z-Wave NWK layer manages the network establishment using command frames known as the Z-Wave Protocol Command Class (Refer to [22] in section “Command frames”). These Z-Wave NWK commands are designed for network formation specific purposes.

The Z-Wave application layer is responsible for building applications using dedicated Command Classes, (defined in [11]-[14]). In order to be certifiable, applications **shall** comply with Z-Wave device types defined in [1] and [15]. Finally, the applications layer is also responsible for providing some network management functionalities using the NWK interface (for details, refer to [2]).

## 4.2 Network Layer Reference Model

The Network Layer (NWK) provides an interface between the application layer and the MAC layer. The NWK layer relies on services provided by the MAC layer and offers services to higher layers through the Network Layer Data Entity (NLDE) and Network Layer Management Entity (NLME) service point interfaces. The NLME provides management service interface where the NWK layer management functionalities can be invoked. The NLME is responsible for maintaining a Network Information Base (NIB) that contains the routing information of the network. Figure 2 illustrates the components and interface of NWK layer.

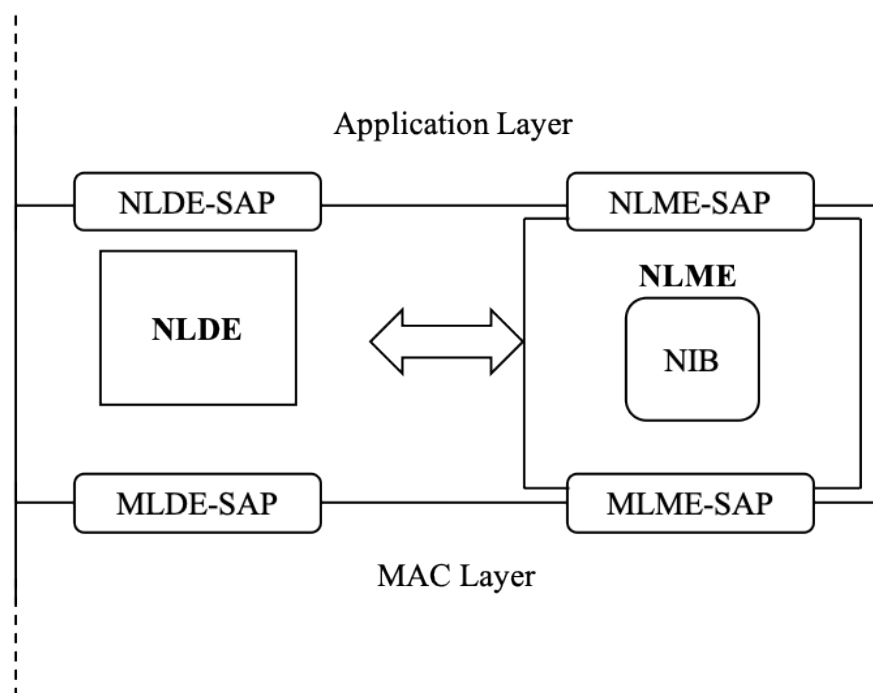


Figure 2. The Network Layer Reference Model

The Z-Wave NWK layer **shall** provide two services to the Application layer that are accessed through two SAPs:

- The data service, accessed through NLDE-SAP, and
- The network management service accessed through the NLME-SAP.

The detailed description of the Z-Wave NWK functional model is presented in [22], chapter “Z-WAVE NETWORK LAYER SPECIFICATION”.

## 4.3 Z-Wave Definitions

### 4.3.1 Z-Wave Network Topology Basic Principles

The following is a summary of the basic Network topology principles established by ITU-T G.9959 [25]:

1. Groups of nodes are divided into domains:
  - The division of physical nodes into domains is logical. Domains may fully or partially overlap each other's radio frequency ranges.
  - The Z-Wave Network Layer supports up to  $2^{32}$  domains.
  - Each domain is identified by a unique **HomeID**.
  - Management of different domains in the same physical media is handled by individual domain masters.
2. The domain is a set of nodes connected to the same medium:
  - One node in the domain operates as a domain master, known as the Primary Controller.
  - Each domain may contain up to 232 nodes (including the domain master).
  - Each node in the domain is identified by a **NodeID** that is unique within the actual domain.
  - Nodes of the same domain can communicate with each other either directly or via other nodes in the same domain.
3. Nodes of different ITU-T G.9959 [25] domains:
  - The Z-Wave Network Layer provides connectivity within one domain.  
In some cases, frames from a foreign domain are repeated into the current domain.
4. The network is self-healing:
  - Nodes may autonomously establish new routes on demand.  
Full mesh routing is supported. There is no requirement for star or tree network topologies.

### 4.3.2 Controller and End Devices

The Z-Wave network layer defines two networking node types: controller and end devices.

The controller nodes are responsible for setting up and maintaining the Z-Wave network. They can include or exclude nodes and they are aware for the network topology. This allows controllers to determine the possible routes between any two nodes in the network. Controllers can exchange network topology with each other.

End devices can only be added or removed from a network by a controller, they do not calculate routes, and they simply rely on route information provided by the controllers. Note that end devices can send commands to other nodes and “control” other nodes functionalities at the application level.

Both controller and end devices can participate in mesh routing. It enables nodes within a network to communicate with each other even when they are out of direct communication range.

### 4.3.3 Network Topology

The network topology refers to the list of nodes present in a network as well the list of direct range neighbors for each node.

Figure 3 illustrates the concept of network topology.

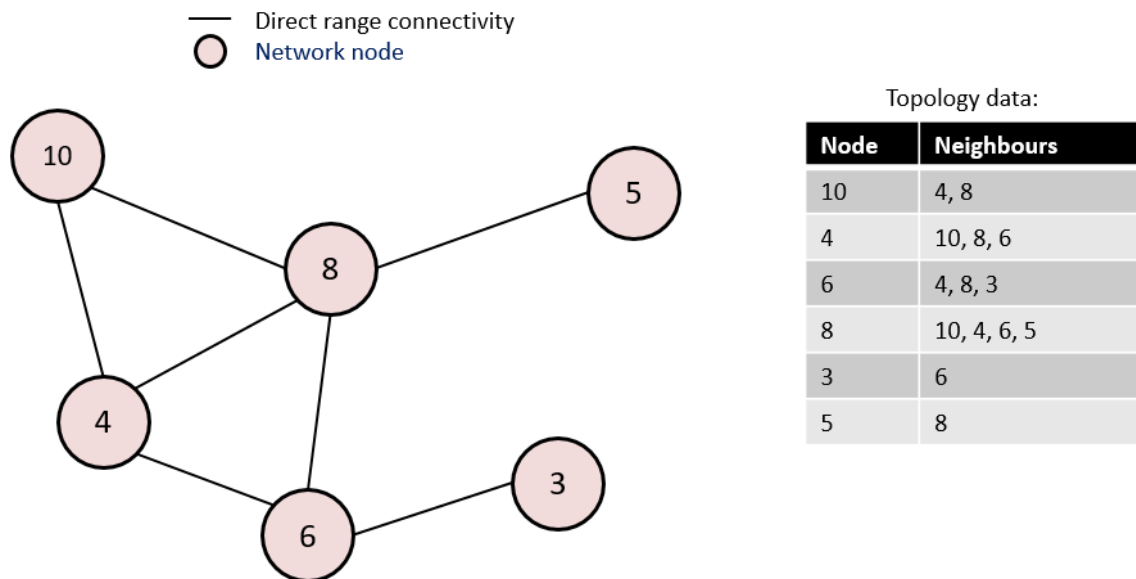


Figure 3. Network Topology Example

### 4.3.4 Z-Wave Controller Roles

A Z-Wave controller is a node that has the capability to provide network management functionalities such as adding/removing nodes to/from a network and distributing network topology to other controllers. The NWK layer defines several controller roles in a network:

### 4.3.5 Primary Controller

The Primary Controller is by default the controller that starts the network. The Primary Controller can always be used to set up and maintain a network. It can add/remove nodes and knows the network topology.

There can be only one Primary Controller in a network.

The Primary Controller may offer additional services to other controllers:

A Primary Controller can handover the Primary Controller (and/or SUC/SIS) role to another controller.

#### 4.3.5.1 Secondary Controller

All controllers that are not the Primary Controller are Secondary Controllers.

If the Primary Controller does not have any SUC/SIS capability, a Secondary Controller cannot include nodes, exclude nodes, or receive updated network topology automatically.

If a SUC is present in the network, a Secondary Controller can request updated network topology at any time.

#### 4.3.5.2 SUC Controller

A Static Update Controller (SUC) is the controller that has the responsibility to keep the network topology and distribute it to other controllers, on demand.

There can be only one SUC in a network. Both Primary Controllers and Secondary Controllers can be SUC.

#### 4.3.5.3 SIS Controller

A SUC ID Server (SIS) Controller is a controller that has both the SUC Controller role and the Primary Controller role. In addition, it provides the SIS functionality. The SIS functionality consists in the ability to reserve NodeIDs to other controllers for enabling them to include and exclude nodes.

#### 4.3.5.4 Inclusion Controllers

If the Primary Controller is the SIS, Secondary Controllers in the same network become Inclusion Controllers. Inclusion Controllers are secondary controllers that can include and exclude nodes on behalf of the SIS.

### 4.3.6 Node Operation Modes

Z-Wave nodes may operate in three different receiving modes.

#### 4.3.6.1 Always Listening (AL)

AL nodes' RF receiver is always on and these nodes participate in mesh routing by repeating Routed NPDUs and Explore NPDUs. Refer to [22] in section "Routed NPDUs" and "Explore NPDUs".

#### 4.3.6.2 Frequently Listening (FL)

FL nodes' RF receiver is turned off most of the time. The RF receiver is turned on at regular intervals for a short duration to listen the Wake Up Beams. AL nodes can reach FL nodes by issuing a Wake Up Beam prior to issuing commands to the FL nodes.

FL nodes do not participate in routing and do not repeat Routed NPDUs and Explore NPDUs. Refer to [22] in section "Routed NPDUs" and "Explore NPDUs".

ITU-T G.9959 [25] defines two possible Wake Up intervals FL nodes: 250ms and 1000ms, and three channel configurations.

When operating with a channel configuration 1 and 2, some NWK commands/frames indicate which setting to use (250ms or 1000ms).

When operating with channel configuration 3, the 1000ms setting is always used in frames/commands, despite using fragmented beams.

For more details, refer to [25].

#### 4.3.6.3 Non-Listening (NL)

NL nodes cannot be awakened by another node. They wake up and transmit frames at fixed configured intervals to a single NodeID destination.

NL nodes reporting can be configured using the Wake Up Command Class. For more details, refer to [12].

#### 4.3.7 Network Addressing

Z-Wave supports the following types of addressing:

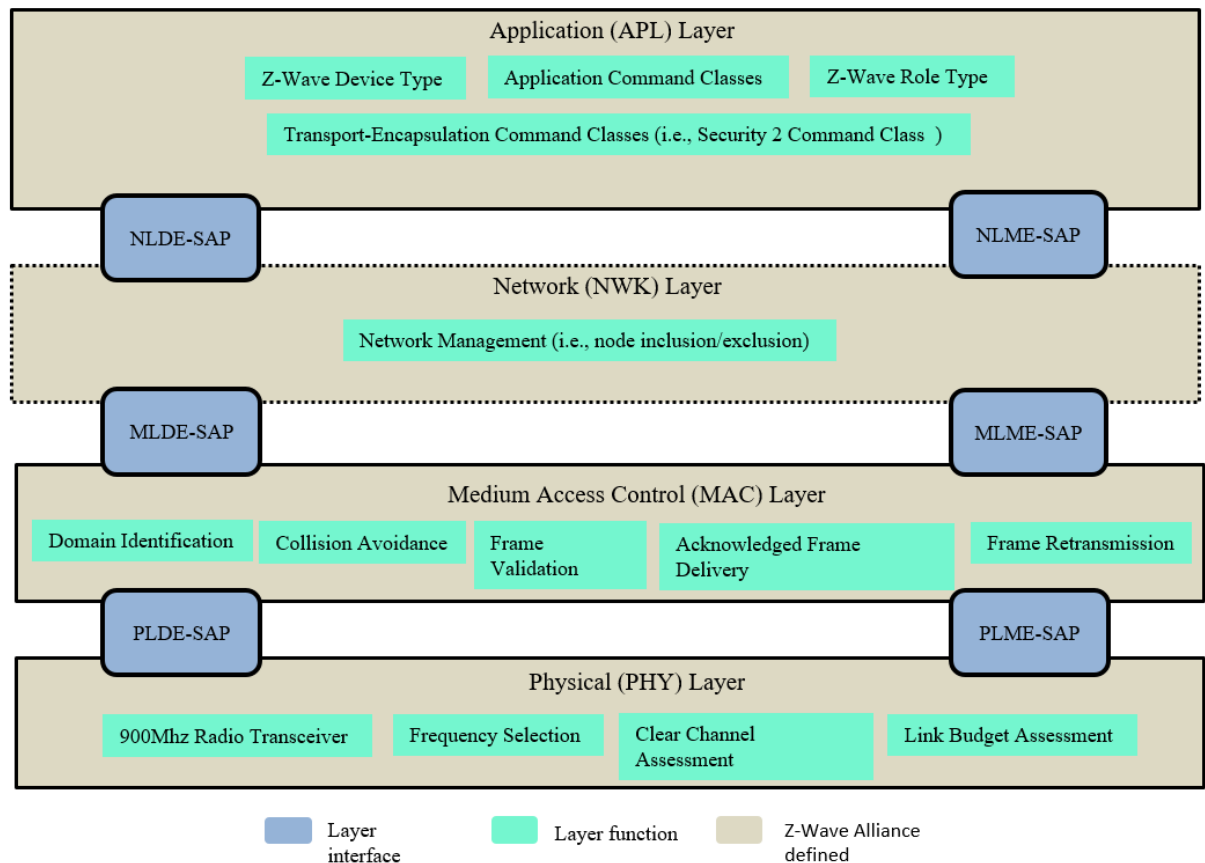
- Singlecast
- Multicast
- Broadcast

The type of addressing and its frame format are defined in the MPDU Header (refer to [25]). Broadcast may only be used in direct range. Broadcast and multicast may be used to reach more than one destination address. In case of multicast, the same payload will be delivered to selected devices only. It is mandatory that multicast always use single cast follow up to ensure devices are reached out of direct range.

## 5 Z-Wave Long Range Protocol Overview

### 5.1 The Z-Wave Long Range Protocol Stack Architecture

The Z-Wave Long Range protocol stack is similar to the Z-Wave protocol stack. This is illustrated in Figure 4.



**Figure 4. Z Wave Long Range Protocol Stack Architecture**

Each layer has two main interfaces to facilitate the communication with upper layers through an SAP. The interfaces are described as a data entity and management entity that provide a data transmission service and all other services, respectively.

“Z-Wave Long Range PHY layer specifications” [23] defines the physical layer and “Z-Wave Long Range MAC layer specifications” [24] defines the medium access control layer.

On the foundation of those two lower layers, the Z-Wave alliance defines the Network layer (NWK) and application layers.

The Z-Wave Long Range NWK layer is responsible for network formation (i.e., inclusion/exclusion of nodes to/from a network). The Z-Wave Long Range NWK layer manages the network establishment using command frames known as the Z-Wave Long Range Command Class (refer to [22] in section “Command frames”). These NWK commands are designed for network formation specific purposes.

The Z-Wave application layer is responsible for building applications using dedicated Command Classes, (defined in [11]-[14]). In order to be certifiable, applications **shall** comply with Z-Wave device types defined in [1] and [15]. Finally, the applications layer is also responsible for providing some network management functionalities using the NWK interface (for details, refer to [2]).

## 5.2 Z-Wave Long Range Network Layer Reference Model

The Z-Wave Long Range NWK layer provides an interface between the application layer and the MAC layer. The Z-Wave Long Range NWK layer relies on services provided by the MAC layer and offers services to higher layers through the Network Layer Data Entity (NLDE) and Network Layer Management Entity (NLME) service point interfaces. Figure 2 illustrates the components and interface of the Z-Wave Long Range NWK layer.

The Z-Wave Long Range NWK layer **shall** provide two services to the Application layer that are accessed through two SAPs:

- The data service, accessed through NLDE-SAP, and
- The network management service accessed through the NLME-SAP.

For a detailed description of the Z-Wave Long Range NWK functional model refer to [22] in section “Z-WAVE LONG RANGE NETWORK LAYER SPECIFICATION”.

## 5.3 Z-Wave Long Range Definitions

### 5.3.1 Z-Wave Long Range Network Principles

The following is a summary of the network principles established by [23] and [24]:

1. Groups of nodes are divided into domains:
  - The division of physical nodes into domains is logical. Domains may fully or partially overlap each other's radio frequency ranges.
  - The Z-Wave Network Layer supports up to  $2^{32}$  domains.
  - Each domain is identified by a unique **HomeID**.
2. The domain is a set of nodes connected to the same medium:
  - Each domain may contain up to *4000* nodes.
  - Each node in the domain is identified by a **NodeID** that is unique within the actual domain.
  - Nodes of the same domain can only communicate with the controller using direct range transmissions.



### 5.3.2 Controller and End Devices

Refer to 4.3.4 Z-Wave Controller Roles

### 5.3.3 Network Topology

Refer to 4.3.3 Network Topology

Nodes added to a network using Z-Wave Long Range will only have one known neighbor, which is the Primary Controller.

### 5.3.4 Z-Wave Controller Roles

Refer to 4.3.4 Z-Wave Controller Roles

A controller starting a Z-Wave Long Range network **shall** assume the Primary controller role.

The SUC/SIS functionalities will not be used in a Z-Wave Long Range network and included controllers will be Secondary Controllers.

### 5.3.5 Node operation modes

Refer to 4.3.6 Node Operation Modes

### 5.3.6 Network Addressing

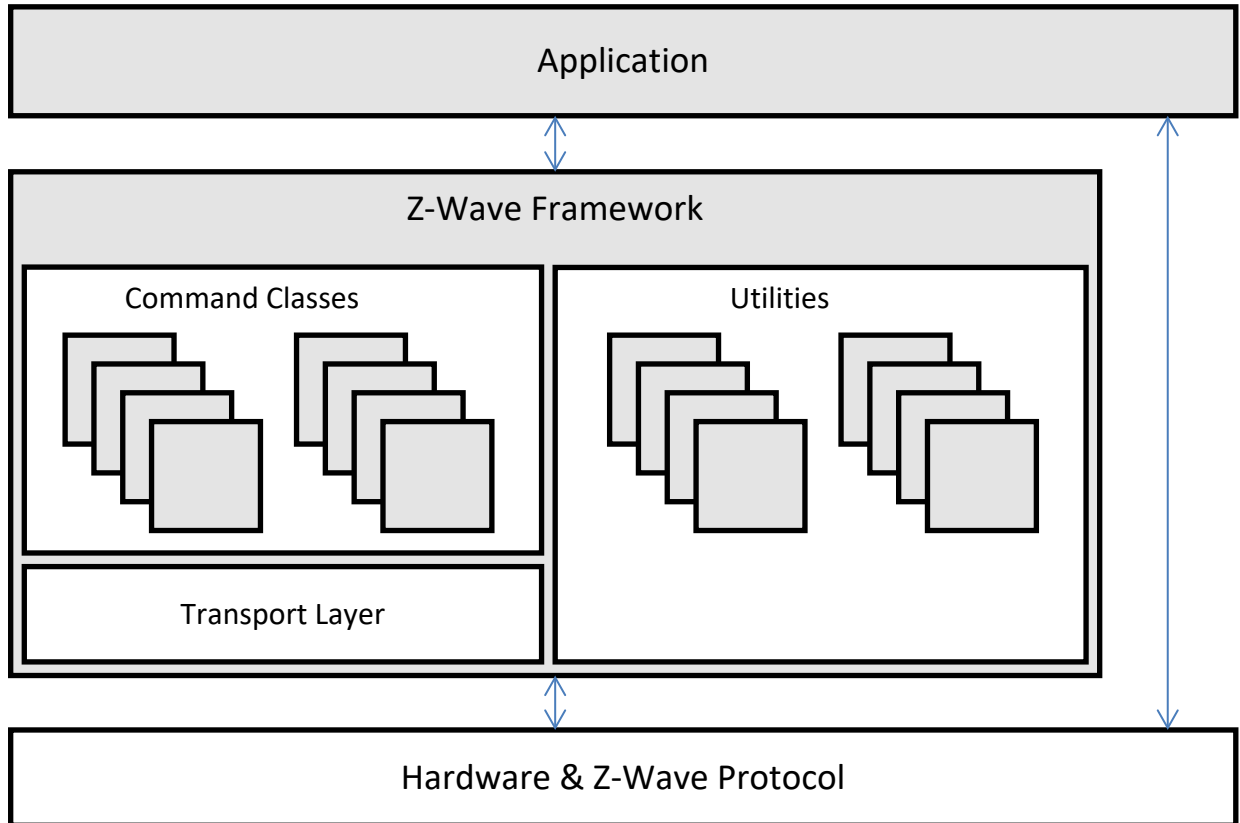
Z-Wave Long Range supports the following type of addressing:

- Singlecast
- Broadcast

The type of addressing and its frame format are defined in the MPDU Header (refer to [24]).

## 6 Architecture

Figure 5 shows the architecture of the ZAF and its relation to the hardware and the Z-Wave protocol.



**Figure 5. The Z-Wave Plus Application Framework Architecture**

The ZAF consists of three blocks:

- **Transport Layer:**  
This layer handles all communication with the protocol, which includes single cast, multicast, Multi-Channel encapsulation, delivery of bundled commands, etc.
- **Command Classes:**  
These modules parse and compose Command Class frames.
- **Utilities:**  
Utilities are composed of different modules including those that are used for handling I/O communication specific for the WSTK and BRD 8029 boards bundled with the SDK. Other modules are battery monitoring and firmware updating, etc.

The framework implements an event-driven application design.

The framework provides built-in features for developing simpler applications. Transmit buffers are mutex-protected to ensure that the application has only one transmit request job (unsolicited event) at a time. The transmit buffer is released only when the transmit request job is completed or has timed out. The Framework can handle one request job and one response job at the same time.

The ZAF is split into the following two folders:

- `/CommandClasses/` contains CC modules. All CC modules share a protected transmit buffer provided by the `ZW_tx_mutex` module. The `ZW_tx_mutex` module implements two transmit buffers, one for request calls and one for response calls.
- `/ApplicationUtilities/` contains utility modules and interfaces to the transport layer. Some of the modules are used for simple MMI-setup such as button and LED handling. Other modules like `association_plus`, `battery_monitor`, `battery_plus`, and `ota_util` are more complex utility modules which interface to CC and the client application.

## 6.1 Application Memory Constraints

The following memory resources are available for certified application development including Z-Wave Framework and Utilities:

- 64 kB of Flash memory for executable code
- 8 kB of RAM for temporary data

The above limitations MUST NOT be exceeded. Violating the limitations may impair compatibility with future SDK versions.

The code space usage for the distributed certified applications are given as example for the beta release:

Application SDK 7.00.00 Beta	Binary Total	Application	Framework (ZAF)	Utilities (Components)
DoorLockKeyPad	180256 bytes	4139 bytes	24197 bytes	2326 bytes
Powerstrip	186064 bytes	3832 bytes	28259 bytes	2326 bytes
SensorPIR	181884 bytes	2546 bytes	26559 bytes	2326 bytes
SwitchOnOff	177684 bytes	2211 bytes	22667 bytes	2326 bytes
WallController	179788 bytes	3355 bytes	22907 bytes	2326 bytes

The certified DoorLockKeyPad application need 4139 bytes + 24197 bytes + 2326 bytes = 30662 bytes out of the 64 kB allocated for the Application, Framework and Utilities. In addition, a separate OTA buffer is allocated for firmware update.

The bootloader resides in separate 10 kB storage area and is not part of the certified application.

Note: The numbers listed under sub-modules (the last three columns) are the raw object file code sizes. The linker will remove unused functions/code and result in a slightly smaller actual code space usage.

The application code space usage can be found in the `.map` file in Simplicity Studio:

[https://www.silabs.com/community/mcu/32-bit/knowledge-base.entry.html/2016/03/07/interpreting\\_thegcc-BpRD](https://www.silabs.com/community/mcu/32-bit/knowledge-base.entry.html/2016/03/07/interpreting_thegcc-BpRD)

## 6.2 Smart Start

The Smart Start feature is part of the protocol and automatically handles the inclusion process without having a user physically interact with a device. When powered on for the first time, the device tells the world that it is ready for inclusion and most likely a controller nearby will hear this and include the device. If inclusion process times out, it retries again after a given time.

### 6.2.1 Starting Smart Start Inclusion

The Smart Start inclusion process starts when the application invokes “ZAF\_setNetworkLearnMode()” with the parameter “E\_NETWORK\_LEARN\_MODE\_INCLUSION\_SMARTSTART”.

The Z-Wave protocol informs the application about the status of inclusion using the command status handler with the following events:

- EZWAVECOMMANDSTATUS\_NETWORK\_LEARN\_MODE\_START
- EZWAVECOMMANDSTATUS\_LEARN\_MODE\_STATUS

The EZWAVECOMMANDSTATUS\_NETWORK\_LEARN\_MODE\_START event contains a status telling whether the inclusion was started successfully.

The EZWAVECOMMANDSTATUS\_LEARN\_MODE\_STATUS event can contain several different statuses:

- ELEARNSSTATUS\_SMART\_START\_IN\_PROGRESS
- ELEARNSSTATUS\_LEARN\_IN\_PROGRESS
- ELEARNSSTATUS\_LEARN\_MODE\_COMPLETED\_FAILED
- ELEARNSSTATUS\_LEARN\_MODE\_COMPLETED\_TIMEOUT
- ELEARNSSTATUS\_ASSIGN\_COMPLETE

The status ELEARNSSTATUS\_SMART\_START\_IN\_PROGRESS indicates that the process of smart start inclusion to a controller has commenced.

The status ELEARNSSTATUS\_LEARN\_IN\_PROGRESS indicates that the process of classic inclusion to a controller has started.

If the status is ELEARNSSTATUS\_LEARN\_MODE\_COMPLETED\_FAILED, the application must reset its NVM and reboot.

If the status is ELEARNSSTATUS\_LEARN\_MODE\_COMPLETED\_TIMEOUT, the application must re-enter the Smart Start inclusion process.

### 6.2.2 Configuring Smart Start Inclusion

When an end device is in smart start it will send out several inclusion request with increasing delay between. By default, the maximum inclusion request interval is set to 512 seconds.

The maximum inclusion interval can be changed from the application. A higher value might be used in battery powered products to save battery power if it is expected that the product will be in smart start inclusion for a long time. A lower value might be used to ensure a faster smart start inclusion when power consumption is not an issue.

The command for changing the maximum inclusion interval is:

Function:

- ***void ZAF\_SetMaxInclusionRequestIntervals(uint32\_t intervals)***

Function for setting the maximum inclusion request delay.

Parameter:

- ***uint32\_t intervals***

Maximum inclusion request delay in 128 seconds steps. Valid range is 5-99

The inclusion requests will be sent out on interval shown in the table below:

<i>Request number</i>	<i>Delay since last inclusion request</i>
0 (Power up)	0 sec
1	Random(0..16 sec)
2	Random(16..32 sec)
3	Random(32..64 sec)
4	Random(64..128 sec)
5	Random(128..256 sec)
6	Random(256..512 sec)
..	..
X	Random(Interval*64..interval*128 sec)

### 6.3 Power Management

Power management is handled by the Z-Wave protocol. All listening devices are prevented by the protocol from entering any energy mode other than EM0 and EM1. Listening Sleeping End Devices can enter energy modes EM0-EM2, while non-listening devices can enter the EM0-EM2 modes and the EM4-hibernate mode.

A new module is introduced in the ZAF/ApplicationUtilities called PowerManagement. This module is used to communicate to the protocol if a Listening Sleeping End Device or non-listening application wants to stay awake for a given time. The module makes it possible to register so-called Power Locks that when enabled prevent the processor from going into a low power mode. A power lock can be set to time out after a selectable number of milli seconds or can be enabled indefinitely until cancelled by a new function call. (Indefinite power locks are enabled by setting the timeout value to zero.)

Power Locks are registered in one of two types of configurations described in the table below:

<i>Power Lock configuration</i>	<i>Description</i>
PM_TYPE_RADIO	Prevents Listening Sleeping End Devices and non-listening devices from entering other energy modes than EM0 and EM1. This means that the radio transceiver will stay operational.
PM_TYPE_PERIPHERAL	Prevents non-listening devices from going to deeper sleep than EM2. The radio transceiver is not operational in EM2 but the Low Energy Peripherals are.

For further details, refer to section 9.6.

### 6.4 True Status Module

The True Status module implements the requirements for **Lifeline Reports** as specified in document “Z-Wave Plus v2 Device Type Specification” [15].

The main components of the True Status module are described in the following sub-sections.

#### 6.4.1 True Status Engine (TSE)

The True Status Engine component is located in the ZAF\_ApplicationUtilities\_TrueStatusEngine folder and consists of the following source files:

- ZAF\_TSE.c
- ZAF\_TSE.h

TSE implements the functionality for registering and handling the state change events that a node wants to report to its lifeline association group members.

A state change can be triggered by a command from a remote node, or by a local change (e.g., a button press).

#### Public functions:

- ***bool ZAF\_TSE\_Init();***

Function for initializing the True Status Engine. Called by the ZAF during initialization.

- ***bool ZAF\_TSE\_Trigger(void\* pCallback, void\* pData, bool overwrite\_previous\_trigger);***

Function for registering state change events and triggering the report to be sent to lifeline group members after a predefined delay. The delay is currently defined to 250 ms. The delay is a means to prevent network collisions and to avoid generation of redundant reports from rapid state changes.

The function also takes care of sending the report to the relevant lifeline group members only; i.e., it will **not** send the report to a lifeline destination that issued the command causing the state change. The current implementation can hold up to 3 different state change requests in a queue awaiting the predefined delay to expire. Additional requests during this period will be discarded.

#### Arguments:

- **pCallback:** Pointer to a callback function for sending the state change report to the lifeline group members. (Described in more details in the next section).
- **pData:** Pointer to a data struct that will be passed in argument to the pCallback function. The pData pointed struct MUST first contain a RECEIVE\_OPTIONS\_TYPE\_EX variable indicating properties about the received frame that triggered the change. Local changes must also include a RECEIVE\_OPTIONS\_TYPE\_EX in the pData struct.
- **overwrite\_previous\_trigger:** Boolean parameter indicating if a previous trigger with the same pCallback and the same source endpoint in the pData struct should be discarded or not. Set it to true to overwrite previous triggers and false to stack up all the trigger messages.

Returns true if success. False if the request could not be handled (queue is full).

### 6.4.2 True Status Callback Functions

The True Status Callback Functions consist of several functions that implement the functionality for sending the actual state change reports to the lifeline association group members. These functions are implemented in each of the relevant command class modules.

The True Status Callback Function is one of the arguments passed to the **ZAF\_TSE\_Trigger()** function (described in the previous section), and it will be executed by the True Status Engine for sending the state change reports to each of the relevant members of the lifeline group, one at a time.

An example of a True Status Callback Function implementation can be found in the Command Class BinarySwitch:

```
void CC_BinarySwitch_report_stx(TRANSMIT_OPTIONS_TYPE_SINGLE_EX txOptions,  
s_CC_binarySwitch_data_t* pData);
```

**Arguments:**

- **txOptions:** Tx Options passed from the True Status Engine with the required destination parameters for sending the state change report to a given lifeline member.
- **pData:** Pointer to the data struct previously registered at the call to **ZAF\_TSE\_Trigger()**. Contains the command data for the report to be sent.

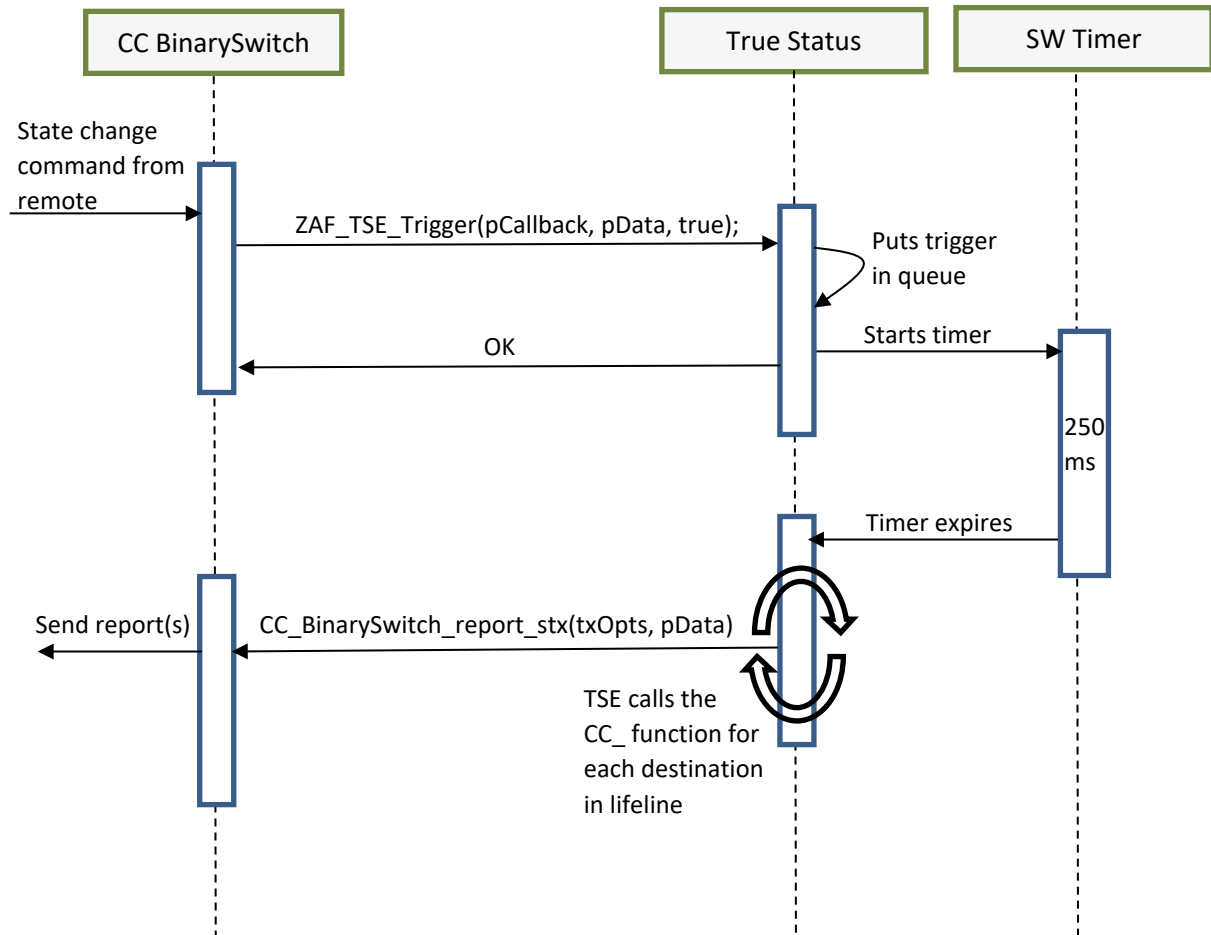
It is important to note that a True Status Callback Function must only send the state change reports by single-cast addressing, not by multicast. Therefore, be sure to use only the **Transport\_SendRequestEP()** transmit function for this purpose as it is also done in the **CC\_BinarySwitch\_report\_stx()** implementation.

**6.4.3 True Status Sequence Flows**

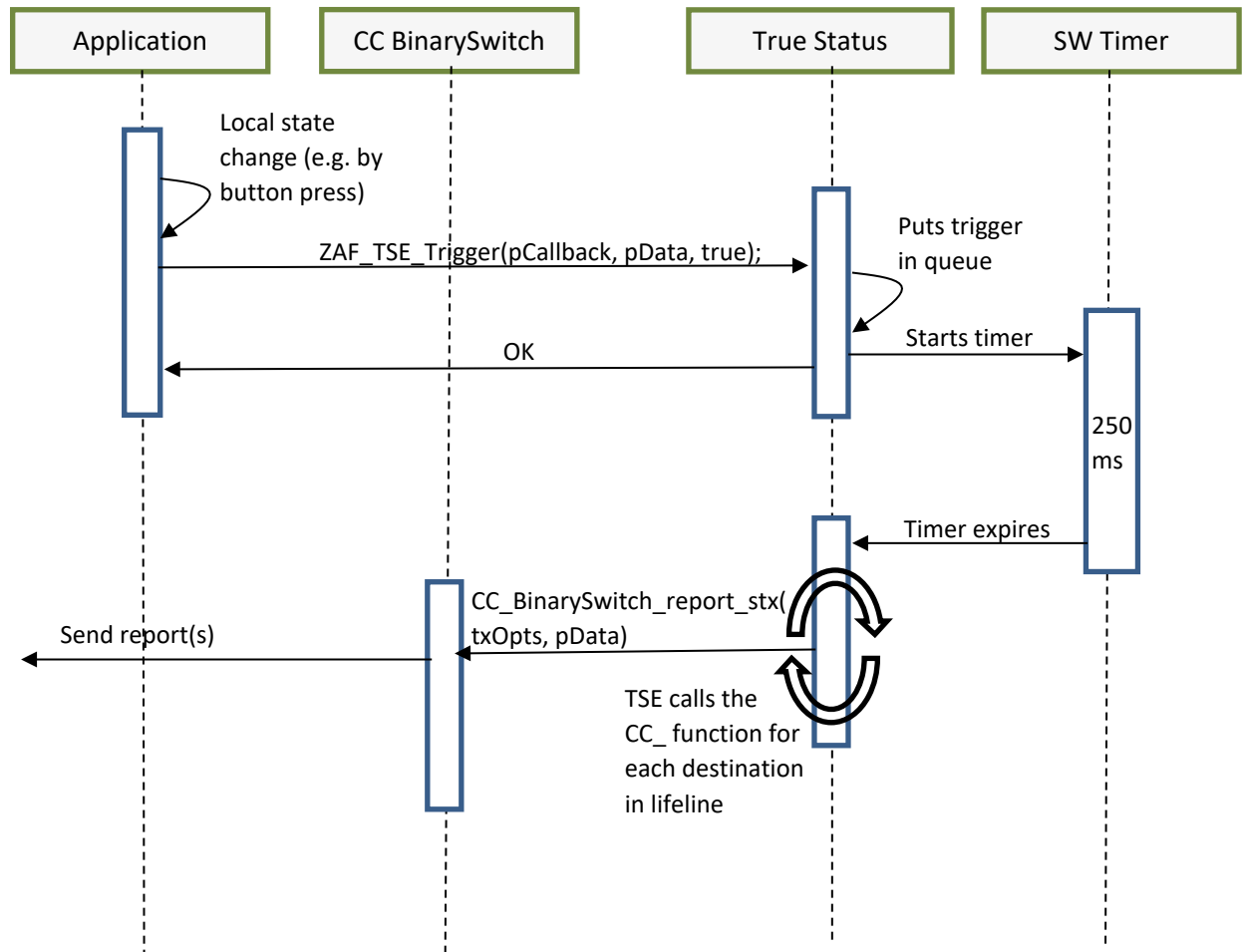
The following diagrams show the function call flows for a BinarySwitch example for the two use cases: 1) state change triggered by a command from a remote node, and 2) state change triggered by a local change (e.g., a button press).



#### 6.4.3.1 Use Case 1 – State Change Triggered by a Command from a Remote Note



### 6.4.3.2 Use Case 2 – State Change Triggered by a Local Change



## 7 How to Develop A Z-Wave Plus Application

The Z-Wave Plus application's basic functionality is defined by the device type and role type, which are explained further in [15] and [2]. It is important to determine the right combination of device type and role type for your Z-Wave Plus application.

Once the device and role types are determined, the application development can start.

### 7.1 Create Application Folder and Set Up Build Environment

#### 7.1.1 Select the Application to Start With

Pick one of existing software samples and modify it to match your needs. Refer to chapter 5 in [20] for more details. Selection should be made mainly based on Role Type:

- Always On End Device: SwitchOnOff, WallController, PowerStrip
- Reporting Sleeping End Device: SensorPIR
- Listening Sleeping End Device: DoorLock

In addition, there are some additional options to consider:

- Endpoint implementation is supported by Power Strip.
- Association groups are implemented in Wall Controller.

#### 7.1.2 Create New Simplicity Studio Project

Follow these steps to set up a working directory for your application:

1. Get a general understanding of the build environment, refer to [3] for more information.
2. Select one of the applications and create an example project in Simplicity studio.
3. Rename imported application to a suitable name for your application by renaming the root folder, i.e. to `<MyApp>`.
4. Navigate in to the `<MyApp>/src` folder and rename `.c` file to `<MyApp>.c`.
5. As for any other example, search for `APP_FREQ` and replace it with the frequency you are using. For more details, refer to chapter 6 in [3].
6. Build the application to verify that the changes did not break anything. It is also possible to download the application to the chip to check that the application runs without error.

### 7.2 Setting Up config\_app.h

#### 7.2.1 Generic Type, Specific Type, and Device Options

A Z-Wave Plus device must specify a Generic Device Class and a Specific Device Class by using the following two definitions:

- `GENERIC_TYPE`
- `SPECIFIC_TYPE`

Refer to [8] and [15] to select the appropriate Generic and Specific Device Classes for your product. The identifiers values are defined in *ZW\_classcmd.h*.

DEVICE\_OPTIONS\_MASK is a bitmask used to specify a set of device options. See the *ZW\_basis\_api.h* file for details.

### 7.2.2 Role Type, Node Type, Icon Type, and User Icon Type (Z-Wave Plus Info CC)

The Role Type, node type, icon type, and user icon type are all values used by the Z-Wave Plus Command Class. They are set using the following definitions:

- APP\_ROLE\_TYPE
- APP\_NODE\_TYPE
- APP\_ICON\_TYPE
- APP\_USER\_ICON\_TYPE

For further information about the Icon Types used in the Z-Wave Plus Info CC, refer to [4]. Contact the Z-Wave Alliance to acquire new Icon Types.

### 7.2.3 Manufacturer Specific CC / Firmware Update

The Manufacturer specific CC requires some product specific values to be defined. Refer to the Manufacturer Specific Command Class in [12] for more information. The ZAF uses the following macros for these values:

- APP\_MANUFACTURER\_ID
- APP\_PRODUCT\_TYPE\_ID
- APP\_PRODUCT\_ID

The Firmware Update Command Class uses this definition:

- APP\_FIRMWARE\_ID: The firmware ID consists of the product type ID and the product ID.

The manufacturer and product IDs are used to identify a Z-Wave product from a manufacturer point of view. Other applications can also use this information to show a company logo, type of product, user guide, etc. on the user interface. This information is exchanged via the Manufacturer Specific CC and currently allocated manufacturer IDs are listed in the *ZW\_classcmd.h* file. See [12] for more information about these two Command Classes.

### 7.2.4 Association Group Information (AGI)

Refer to [12] and [6] for a general understanding of AGI and Associations.

In an application, the AGI must be configured in *config\_app.h*.

For Z-Wave Plus products, the Lifeline group is mandatory. It can be defined using the following declaration:

```
#define AGITABLE_LIFELINE_GROUP \
{<command class X>, <command A>}, \
{<command class Y>, <command B>}, \
```

```
{<command class Z>, <command C>}
```

Refer to [15] to find out what events and Command Classes to use in the Lifeline group. Definitions for Command Classes and Commands are found in *ZW\_classcmd.h*.

Other groups (apart from Lifeline) must be defined using the following format if the application is not implementing Multi Channel endpoints:

```
#define AGITABLE_ROOTDEVICE_GROUPS \
{<profile 1 MSB>, <profile 1 LSB>, {<command class X, command A>, "<group 2 name>"}\
{<profile 2 MSB>, <profile 2 LSB>, {<command class X, command A>, "<group 3 name>"}\
```

If the application is implementing Multi Channel endpoints, the AGI definition must be filled out using the endpoint groups. An example of Multi Channel endpoint implementation is Power Strip application.

```
#define AGITABLE_ROOTDEVICE_GROUPS \
AGITABLE_ENDPOINT_1_GROUPS, \
AGITABLE_ENDPOINT_2_GROUPS, \
AGITABLE_ENDPOINT_3_GROUPS, \
AGITABLE_ENDPOINT_4_GROUPS
```

*AGITABLE\_ENDPOINT\_X\_GROUPS* represents the non-lifeline groups for endpoint X. Each of the endpoint groups are defined as the Root Device groups defined by *AGITABLE\_ROOTDEVICE\_GROUPS*, but with a matching definition name, other profiles, Command Classes, etc.

```
#define AGITABLE_ENDPOINT_1_GROUPS \
{<profile X MSB>, <profile X LSB>, {<command class>, <command>, "group name"}, \
{ASSOCIATION_GROUP_INFO_REPORT_PROFILE_CONTROL, \
ASSOCIATION_GROUP_INFO_REPORT_PROFILE_CONTROL_KEY01, {COMMAND_CLASS_SWITCH_MULTILEVEL_V4, \
SWITCH_MULTILEVEL_SET_V4}, "Button 1"}
```

When the product implements Multi Channel endpoints, it must be mapped to the root association groups. Root groups mapping provides backwards compatibility because devices that do not support Multi Channel must be able to ask the Root Device which groups are supported. Root group mapping defines groups in the Root Device mapping to endpoints' groups. An example is given in Table 1.

**Table 1. Root Device and Endpoint Group Mapping**

Root Device Group	Endpoint ID	Endpoint Ggroup ID
Root Device Group 2	Endpoint 1	Endpoint 1 Group 2
Root Device Group 3	Endpoint 2	Endpoint 2 Group 2

The following shows how root group mapping is configured in *config\_app.h*. The details of the root group mapping setup depend on the application.

```
#define ASSOCIATION_ROOT_GROUP_MAPPING_CONFIG \
{<ROOT_DEVICE_GROUP 2>, <ENDPOINT_ID 1>, <ENDPOINT_GROUP 2>}, \
{<ROOT_DEVICE_GROUP 3>, <ENDPOINT_ID 2>, <ENDPOINT_GROUP 2>}
```

Refer to the *config\_app.h* file in the Wall Controller application for a group mapping example. The SensorPIR also shows how AGI can be set up.

Group definitions are used to initialize the AGI in the main source file of the application.

### 7.2.5 Security

Security level is configured in the *config\_app.h* file with the definition of REQUESTED\_SECURITY\_KEYS flag. Definitions can be found in the *ZW\_security\_api.h* file; see [5] for more information about security.

Application security level bits must be specified when developing a product. Security level “No-secure” is the default value.

```
#define REQUESTED_SECURITY_KEYS \ (SECURITY_KEY_S2_UNAUTHENTICATED_BIT|SECURITY_KEY_S0_BIT)
```

Added functionality:

ApplicationSecureKeysRequested() includes security keys flag REQUESTED\_SECURITY\_KEYS.

### 7.3 Setting Up config\_rf.h

The Tx power should be set by modifying the file config\_rf.h to comply with local regulatory authorities. This file contains 2 defines:

```
#define APP_MAX_TX_POWER          0
#define APP_MEASURED_0DBM_TX_POWER 33
```

Where, APP\_MEASURED\_0DBM\_TX\_POWER is for tuning of TX power to 0 dBm in a conducted environment. During the turning process, 'APP\_MAX\_TX\_POWER' should be 0 (0dBm).

APP\_MAX\_TX\_POWER is a value from -100 to +100 deci dBm (-10dBm to +10dBm) and is for adjusting Tx power by the application framework after completion of Tx power tuning.

Valid range is:

```
100 >= (APP_MAX_TX_POWER + APP_MEASURED_0DBM_TX_POWER) >= -100
```

To set maximum power, use:

```
#define APP_MAX_TX_POWER          100
#define APP_MEASURED_0DBM_TX_POWER 0
```

Procedure for setting TX power

- Set APP\_MAX\_TX\_POWER to 0 and set APP\_MEASURED\_0DBM\_TX\_POWER to 0 and compile the application
- Do a conducted measurement of the Tx power with these settings on the product. It is important that this is done on the finished product.
- Set the APP\_MEASURED\_0DBM\_TX\_POWER to the measured, conducted value.

- d) Set the APP\_MAX\_TX\_POWER to the desired/allowed Tx power in the region where the product is to be used.
- e) Compile the firmware
- f) Perform the regulatory radiated measurements with the regulatory limit value (step d), e.g. 50 deci dBm (5 dBm). If the regulatory measurements allow for a e.g. ½ dB more, then change the deci dBm to 55 and re-compile. If the radiation is too high in one direction and e.g. ½ dB less is needed, then change to 45 deci dBm and recompile.

## 7.4 Setting Up Files in Non-Volatile Memory

All applications must open a NVM3 [18] file system that is used by the ZAF for storing files in non-volatile memory. The file system can also be used by applications to store application specific files. The file system is opened by calling the function `ApplicationFileSystemInit(..)` found in `ZAF_nvm3_app.c`.

The application file system occupies an area of 12k bytes in flash. For the file system to function properly in all circumstances it is recommended that one not store more than 4k bytes of data in it, including both application-specific files and files used by ZAF. Application developers must not increase the default size of the application file system (`NVM3_APP_NVM_SIZE`) since it will make it collide with the area used for storing Z-Wave protocol files.

The NVM3 file system uses a cache in RAM for storing the locations of files in flash. By default, the maximum number of files in the cache is set to 10. If the total number of files used by both ZAF and application exceeds 10, `NVM3_APP_CACHE_SIZE` in `ZAF_nvm3_app.c` must be increased accordingly, or the file system will slow down considerably.

Each file in an NVM3 file system must be assigned an individual 20-bit object key as file identifier [18]. The range of integers 0x51000—0x5FFFF have been reserved to be used as file identifiers for the ZAF and must NOT be used for application specific files. Application specific files should preferably use identifiers in the range 0x00000—0x0FFFF.

Each sample application lists the files it uses in an array called `g_aFileDescriptors[]`. The list contains the file identifiers and sizes of the files used by ZAF in the application. Some sample applications also have application-specific files included in the list. On upstart, the application checks if all files in the list are present in the file system. All application file systems must have a file with file identifier `ZAF_FILE_ID_APP_VERSION` that contains the version number of the application. If this file is missing, the file system is considered unwritten or corrupt leading to reformatting of the file system and all files set to default.

To introduce an application-specific file to the file system just define a new 20-bit object key number that is not already in use. The file will be added to the file system once it is first written using the function `nvm3_writeData()` [19].

```
#define FILE_ID_MYNEWFILE (0x00112)

typedef struct SMyAppData
{
    int32_t status;
    uint8_t vector[10];
} SMyAppData;
```

```

SMYAppData wrtData;
wrtData.status = -5;
memset(&(wrtData.vector), 0x55, sizeof(wrtData.vector));

//This call will create and write a file containing wrtData in the file system.
nvm3_writeData(pFileSystemApplication, FILE_ID_MYNEWFILE, &wrtData, sizeof(wrtData));

SMYAppData rdData;

//This call will read the content of the file to rdData. Please be warned that it is
//not possible to read part of the file. If sizeof(rdData) < sizeof(wrtData) above,
//the read function will return an error.
nvm3_readData(pFileSystemApplication, FILE_ID_MYNEWFILE, &rdData, sizeof(rdData));

```

It is recommended that one write default content to application-specific files in the function `SetDefaultConfiguration()` that gets called after formatting the file system.

When performing firmware update, the content of the application file system remains intact. If the file identifiers remain the same, old files used by the previous firmware can still be used. When developing a newer version of the firmware where new files are added or files are changed in any way, it is necessary to increase the `APP_VERSION`, `APP_REVISION` or `APP_PATCH` number in the applications `config_app.h`. The bootloader does not accept files having lower or the same version number. Then, on first upstart of the new firmware, the application will be able to recognize that the file system on the chip belongs to an older version of the firmware by reading the file with identifier `ZAF_FILE_ID_APP_VERSION`.

## 7.5 Watchdog Enable/Disable

The watchdog timer is enabled in the application by default and will reset the device if the application task runs for more than 1 second without releasing the processor.

To disable the watchdog during development, comment out the `WDOGn_Enable()` function call inside the `ApplicationTask` function as shown below:

NOTE: The watchdog should always be enabled in production code but can be disabled in debug build

```

static void
ApplicationTask(SApplicationHandles* pAppHandles)
{
    // Init
    DPRINT("Enabling watchdog\n");
    WDOGn_Enable(DEFAULT_WDOG, true);    <<-- Comment out this line to disable the watchdog
}

```

## 7.6 Source File

The application must implement one function for initialization: `ApplicationInit(..)`. The function is called by the Z Wave main function during system startup and gets the wakeup reason as input argument, see the `ZW_basis_api.h` file. Application specific hardware initializations like pin configuration should be



done from this function. After configuration is finished the function must register an application task by calling `ZW_ApplicationRegisterTask(..)` so that the application can start running.

The application task function, `ApplicationTask(..)`, is registered by FreeRTOS in the list of tasks that are ready to run. In the software examples, `ApplicationTask(..)` first performs application specific initialization of software on startup. Among other things it configures the event distribution functionality with event handlers for different types of events. Subsequently it goes into an eternal loop where it lets the event distributor handle any events. See the description in section 9.5. The FreeRTOS scheduler will ensure that the application task is given processor time according to its priority.

### 7.6.1 Command Class Lists Configuration

The application uses 3 Command Class lists to send out the Node Information Frame (NIF) depending on the inclusion status. These three lists define the NIF for:

- Not included
- Non-securely included
- Securely included

The following Command Class list is used when the node is not included or non-securely included. When the device is included, `Security` and `Security_2` Command Classes are removed by the ZAF. This Command Class list is present in the NIF:

```
static code BYTE cmdClassListNonSecureNotIncluded[]
```

The following Command Class list is used when node is securely included. It represents the Command Classes that are supported non-securely even though the device has been securely included.

```
static code BYTE cmdClassListNonSecureIncludedSecure[]
```

The following Command Class list is used when node is securely included. It contains only the Command Classes that are supported securely. This Command Class list is advertised through the `Security` Command Class, `Security Commands Supported Report` Command.

```
static BYTE cmdClassListSecure[]
```

### 7.6.2 Endpoint Configuration

If your device must implement endpoints, the AGI and association group mapping must be set up in the `config_app.h` file. After configuring each endpoint in AGI (see Section 7.2.4), the `AssociationInitEndpointSupport()` must be called instead of the `AssociationInit()` for association group mapping (see Chapter 9.2.1 for the different initializations).

Finally, the transport layer needs to be initialized for endpoints by calling the `Transport_AddEndpointSupport()` function. This function sets up endpoints' functionalities and Command Class lists. Read [13] for more information about individual and aggregated endpoints.

```
void Transport_AddEndpointSupport(  
    EP_FUNCTIONALITY_DATA* pFunctionality,  
    EP_NIF* pList, BYTE sizeList);
```

## 8 Command Classes

An essential feature of the ZAF is the communication through Command Classes. For this purpose, each of the Command Classes has a C module where incoming commands are handled, and outgoing commands are transmitted.

### 8.1 General Interfacing to CCs

The application will typically use CCs in the two following ways:

- Send an unsolicited command, or
- Respond to a received command

#### 8.1.1 Unsolicited Transmission

See the following example of a CC API definition. Although some of the CCs does not comply with that naming scheme yet, it is the plan that more and more CCs will comply for every future version of the ZAF.

```
job_status_t CC_Basic_Set_tx(  
    agi_profile_t * pProfile,  
    uint8_t sourceEndpoint,  
    uint8_t value,  
    void (*pCbFunc)(transmission_result_t * pTransmissionResult));
```

A controlling device, e.g., a wall switch, may want to send a Basic Set Command. This is the purpose of the function given in the above example. Three of the four arguments are generic arguments found in all Command Class APIs: pProfile, sourceEndpoint, and pCbFunc. These arguments are detailed below. The argument bValue is specific for the Basic Set Command. To find more information about Basic Set or other application CCs and their commands, see [11].

- **pProfile**  
The pProfile points to an AGI profile. This must be one of the profiles that was set up in the AGI section of your application's *config\_app.h* file.
- **sourceEndpoint**  
If the application is implementing endpoints, the source endpoint must be set to ENDPOINT\_X where X is the number of the endpoint, e.g., ENDPOINT\_1. If the application does not have endpoints, the source endpoint must be set to ENDPOINT\_ROOT. The enumeration for ENDPOINT\_ROOT and ENDPOINT\_X can be found in the *ZW\_TransportEndpoint.h* file.
- **pCbFunc**  
This argument is a pointer to a callback function with one argument of the type TRANSMISSION\_RESULT. The definition of this type can be found in the *CC\_Common.h* file. The given callback function will be called once for each node found in the Associations. When the transmission for the last node is done, the *isFinished* value will be set to TRANSMISSION\_RESULT\_FINISHED.

### 8.1.2 Respond to Received Command

Each CC implementation has a *handleCommandClass...()* function that extracts the received frame for a given Command Class. This function needs to be added into the application's *Transport\_ApplicationCommandHandlerEx()* function switch-case block. Normally, the frame is carrying a "Set" or "Get" Command that results in a function call for reading or writing data. It is up to the application to implement these functions provided as external functions in the CC header file.

On the application side, *Transport\_ApplicationCommandHandlerEx()* will figure out which CC should handle incoming frame:

SwitchOnOff.c

```
/* Call command class handlers */
switch (pCmd->ZW_Common.cmdClass)
{
    case COMMAND_CLASS_SWITCH_BINARY_V2:
        frame_status = handleCommandClassBinarySwitch(rxOpt, pCmd, cmdLength);
        break;
```

When the handler of the corresponding Command Class has been triggered, it will process the received frame further:

CC\_Binary\_Switch.c

```
switch (pCmd->ZW_Common.cmd)
{
    case SWITCH_BINARY_GET:
        if(FALSE == Check_not_legal_response_job(rxOpt))
        {
            :
            /* Get the values from the application */
            pTxBuf->ZW_SwitchBinaryReportV2Frame.currentValue =
            appBinarySwitchGetCurrentValue(rxOpt->destNode.endpoint);

            :
```

The CC handler will prepare the Report frame and then go back to the application to get application-specific data:

```
CMD_CLASS_BIN_SW_VAL
appBinarySwitchGetCurrentValue(uint8_t endpoint)
{
    UNUSED(endpoint);
    return onOffState;
}
```

### 8.1.3 CC Version

The version of the Command Class is set within each CC using the macro: `REGISTER_CC(COMMAND_CLASS, CC_VERSION, CC_handler);`

This macro defines the version of CC in a single place and there is no need to set the CC version anywhere else.

In the case of a Binary Switch CC, the version is defined as:

```
REGISTER_CC(COMMAND_CLASS_SWITCH_BINARY, SWITCH_BINARY_VERSION_V2,  
handleCommandClassBinarySwitch);
```

#### 8.1.4 True Status Support

Starting from Z-Wave+ V2, if CC is on the list of mandatory command classes defined in [16], it must support True Status Engine(TSE). See more about TSE in Chapter 6.4.

### 8.2 Implementing a CC

Not all CCs have been implemented in the ZAF yet. Hence, in some cases, the required Command Class must be developed for the application.

### 8.3 Association Group Information CC

For a general introduction to AGI CC, refer to [12].

AGI CC is implemented in two C modules:

- CC\_AssociationGroupInfo
- Agi

Together, these modules serve two purposes:

- Advertise capabilities of each association group, and
- Find associated devices to which the application wants to send an unsolicited command.

#### 8.3.1 API

- CC\_AGI\_Init()
- CC\_AGI\_LifeLineGroupSetup()
- CC\_AGI\_ResourceGroupSetup()

### 8.4 Battery CC

Battery CC is implemented in module CC\_Battery. Additional functionality may be added to the application, if needed. See CC\_Battery\_BatteryGet\_handler() in SensorPIR.c as an example.

## 8.5 Indicator CC

Indicator CC is mandatory since Z-Wave+ V2. It can be used to identify a device in the network, by sending command that will, for example, set the LED indicator to ON over a certain period.

Indicator CC is implemented in module `CC_Indicator`.

## 8.6 Notification CC Version 8

Notification CC is typically used in sensor applications because it supports many different notification/sensor types. For general information related to Notification CC, see [11].

Historically, this CC supported both push and pull mode and the ZAF implementation has tried to cover both modes. However, push and pull mode have been separated in version 8 of the CC and the ZAF now supports and tests only push mode, because supporting both modes at the same time results into a conflict in certification.

Notification CC is implemented by two C modules:

- `CC_Notification`
- `notification`

The Notification CC API consists of the following functions. For information about what they do, arguments, and return values, refer to the source header files of `notification.h`.

- `InitNofication()`
- `AddNotification()`
- `DefaultNotificationStatus()`
- `NotificationEventTrigger()`
- `UnsolicitedNotificationAction()`

The typical call order is showed below:

1. Initialize the Notification CC by calling **`InitNofication()`**.
2. Optionally, set the notification status for all available notifications (limited by the definition `MAX_NOTIFICATIONS` in `config_app.h`) by calling **`DefaultNotificationStatus()`**.
3. Call **`AddNotification()`** a number of times depending on how many different notification types the application implements.
4. Trigger an event by calling **`NotificationEventTrigger()`** and transmit it by calling **`UnsolicitedNotificationAction()`**.
5. If a state was triggered contrary to an event, the state can be cancelled by calling **`NotificationEventTrigger()`** with cancelling arguments and then transmitting the cancellation by calling **`UnsolicitedNotificationAction()`**.

## 8.7 Supervision CC

Refer to [7] for the definition of the Supervision Command Class.

CC Supervision is built into the Application Framework and handles Supervision communication on S2 encapsulated frames. Supervision is only supported for Set and Report commands.

The default setting is that CC Supervision supports only one Supervision Report per Supervision Get command. In Supervision Get command, the 'more status updates' field is set to CC\_SUPERVISION\_STATUS\_UPDATES\_NOT\_SUPPORTED. The application does not need to initialize CC Supervision if the default configuration fulfills application demands.

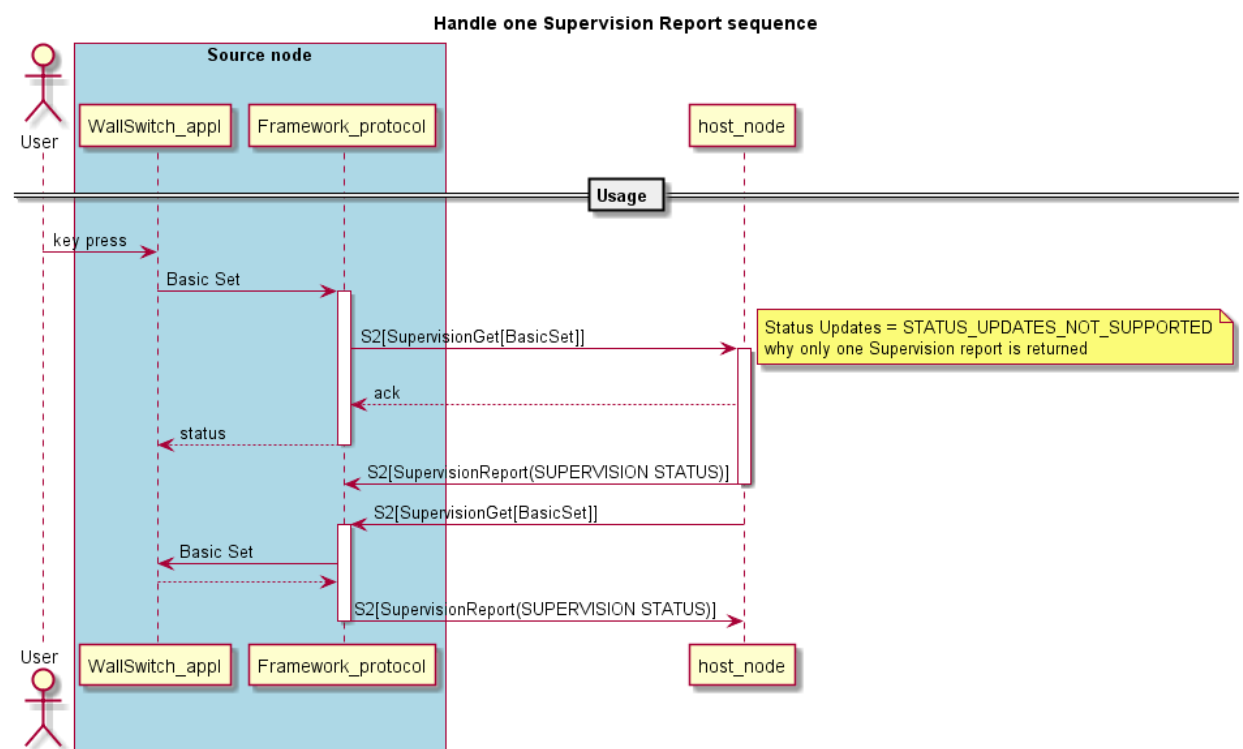
Initialization for CC Supervision:

```
void
CommandClassSupervisionInit( cc_supervision_status_updates_t status_updates,
    void (*pGetReceivedHandler)(SUPERVISION_GET_RECEIVED_HANDLER_ARGS * pArgs),
    void (*pReportReceivedHandler)(cc_supervision_status_t status, uint8_t duration));
```

## 8.7.1 Configuration Scenarios

### 8.7.1.1 Default Configuration

The application does not handle more than one Supervision report. The device receives a Supervision Get and replies with a Supervision Report containing CC\_SUPERVISION\_STATUS\_SUCCESS. There is no need to call CommandClassSupervisionInit() for initialization.



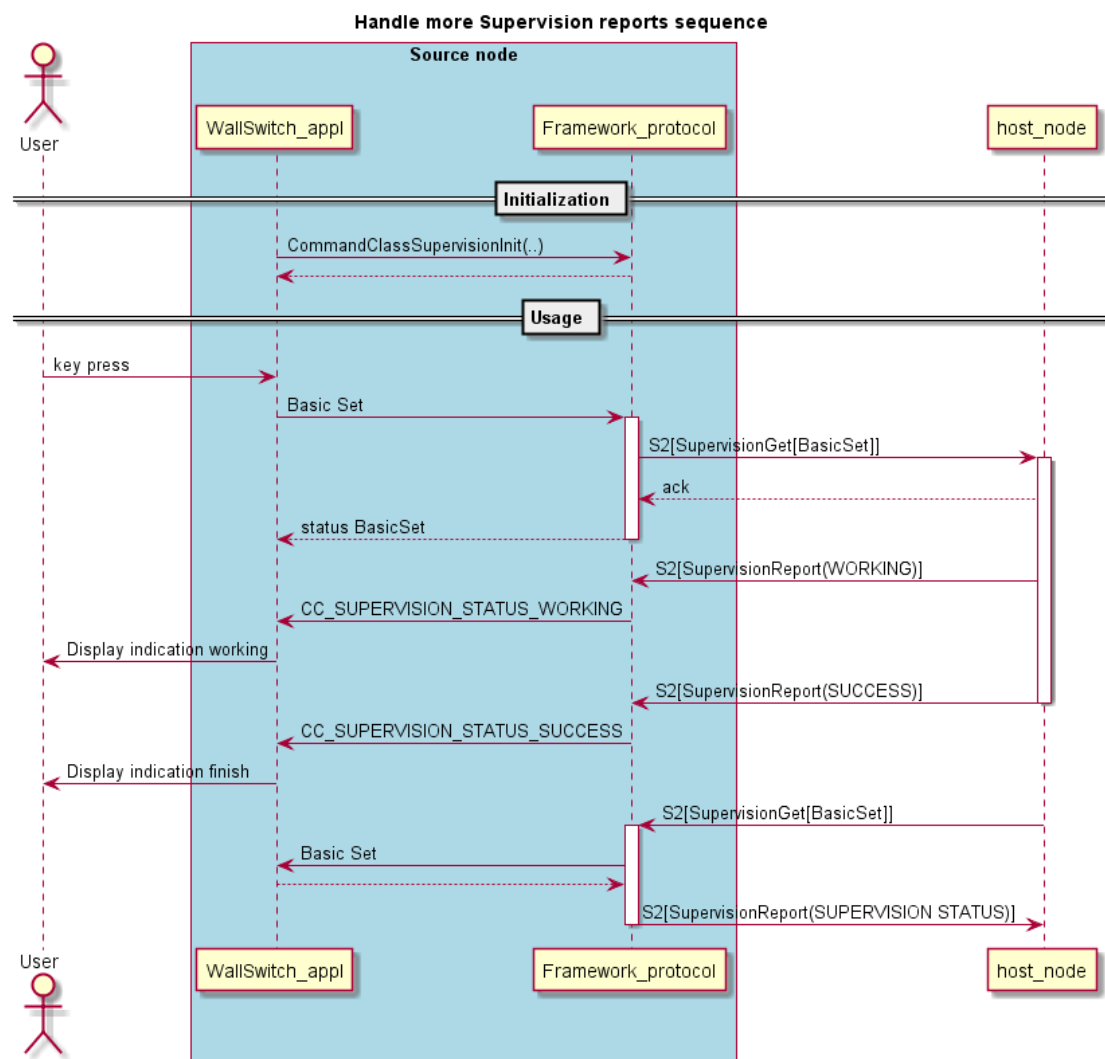
### 8.7.1.2 Handle More Supervision Reports

The application has the capability to display that a destination node is processing the transmitted command. An example is a Wall Controller with a display that shows a working device

(CC\_SUPERVISION\_STATUS\_WORKING) until a given command has been performed (CC\_SUPERVISION\_STATUS\_SUCCESS).

```
void ApplicationInitSW(..)
{
    CommandClassSupervisionInit(
        CC_SUPERVISION_STATUS_UPDATES_NOT_SUPPORTED,
        NULL,
        ZCB_CommandClassSupervisionReportReceivedHandler);
}
```

```
void ZCB_CommandClassSupervisionReportReceivedHandler(cc_supervision_status_t status, BYTE
duration)
{
    :
}
```



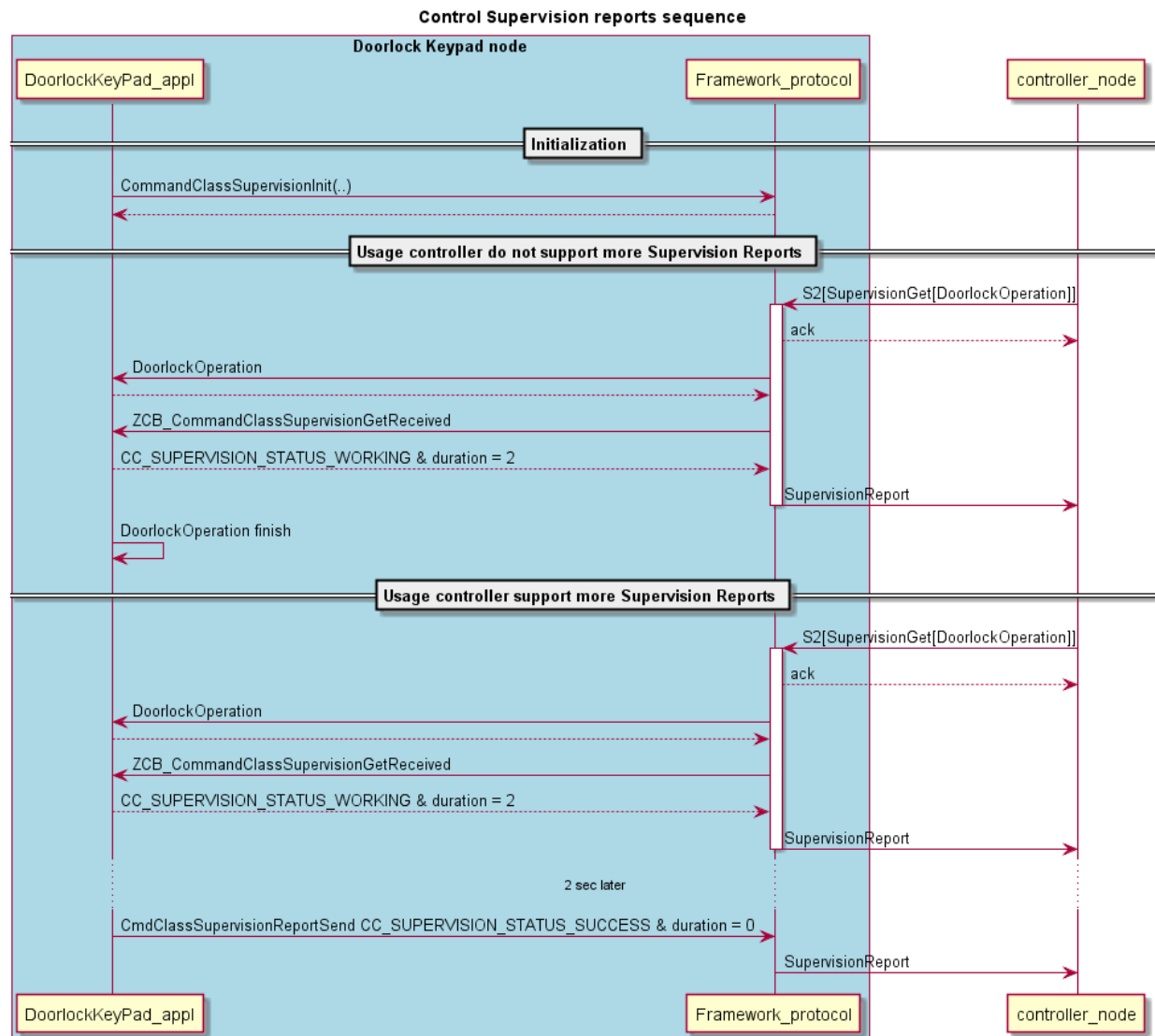


### 8.7.1.3 Control Supervision Reports

The application has the capability to send several Supervision Reports to report on an ongoing activity. An example is a Door Lock Key Pad that reports when a Door Lock Operation is started and when it is finished.

```
void AppStateManager(..)
{
    CommandClassSupervisionInit(
        CC_SUPERVISION_STATUS_UPDATES_NOT_SUPPORTED,
        ZCB_CommandClassSupervisionGetReceived,
        NULL);
}
```

```
void ZCB_CommandClassSupervisionGetReceived(SUPERVISION_GET_RECEIVED_HANDLER_ARGS * pArgs)
{
    :
}
```





## 9 Utilities

Some of the commonly used functionalities are handled by utilities, which can be adapted by the developer for an application.

### 9.1 AGI Module

The AGI module works with the Association Plus module to provide a general API for handling the setup and use of associations between multiple Z-Wave devices. The AGI module interfaces to “CC\_AssociationGroupInfo.h” for external access to AGI tables.

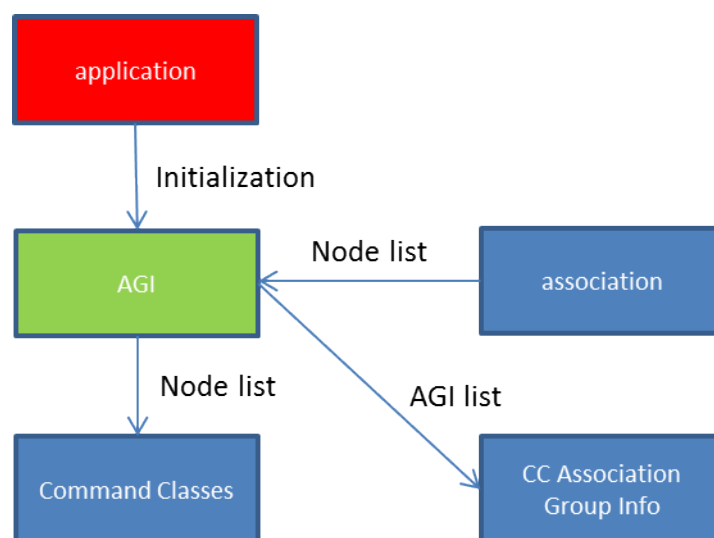


Figure 6. AGI Behavior Diagram

The AGI module contains a configuration part and an API to extract destination devices for a specific association group.

#### 9.1.1 Configuration of AGI

The AGI module has a constructor called *AGI\_Init()*, which needs to be called before the AGI groups are configured. The constructor call resets the module parameters.

```
void AGI_Init(void);
```

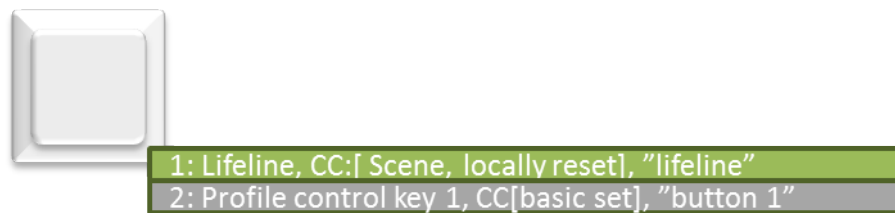
The configuration of group 1 (Lifeline) is done when calling the *CC\_AGI\_LifeLineGroupSetup* function to setup the profile and command class groups. This function is also used to configure each endpoint of group 1 (endpoint Lifeline). For the Root Device configuration, the endpoint parameter must be set to *ENDPOINT\_ROOT* (0):

```
void CC_AGI_LifeLineGroupSetup(
    cc_group_t const * const pCmdGrpList,
    uint8_t listSize,
    uint8_t endpoint);
```

The configuration of group 2..N for endpoint X is done by calling the *AGI\_ResourceGroupSetup* function. The function sets up a list of type *AGI\_GROUP* including profile, Command Class group, and group name. For the Root Device configuration, the endpoint parameter must be set to *ENDPOINT\_ROOT* (0)

```
void AGI_ResourceGroupSetup(
    AGI_GROUP const * const pTable,
    uint8_t tableSize,
    uint8_t endpoint);
```

#### 9.1.1.1 Example 1: How to Set Up AGI for a Wall Controller.



**Figure 7. Wall Controller that sends Command Class Scene and Device Reset Locally over Association group 1 (lifeline) and Command Class Basic over Association group 2**

The applications use definitions from *config\_app.h* to configure *agiTableLifeLine[]* and *agiTableRootDeviceGroups[]*.

**Table 2. Configuration of the Wall Controller**

```
CMD_CLASS_GRP agiTableLifeLine[] =
{
    {COMMAND_CLASS_CENTRAL_SCENE, CENTRAL_SCENE_NOTIFICATION},
    {COMMAND_CLASS_DEVICE_RESET_LOCALLY, DEVICE_RESET_LOCALLY_NOTIFICATION}
};

AGI_GROUP agiTableRootDeviceGroups[] =
{
    {
        ASSOCIATION_GROUP_INFO_REPORT_PROFILE_CONTROL,
        ASSOCIATION_GROUP_INFO_REPORT_PROFILE_CONTROL_KEY01,
        {COMMAND_CLASS_BASIC, BASIC_SET}, "Button 1"
    }
};

void AppStateManager(EVENT_APP event)
{
    switch (currentState) {
        case STATE_APP_STARTUP:
            if (EVENT_APP_INIT == event) {
                AGI_Init();

                CC_AGI_LifelineGroupSetup(
                    agiTableLifeLine,
                    sizeof_array(agitableLifeLine),
                    ENDPOINT_ROOT);

                AGI_ResourceGroupSetup(
                    agiTableRootDeviceGroups,
```

```

        sizeof_array (agiTableRootDeviceGroups),
        ENDPOINT_ROOT);
:

```

### 9.1.1.2 Example 2: How to Extend the Wall Controller with 2 Buttons

In this example, each button represents an endpoint. The Root Device association group 2 is moved to endpoint 1. Root mapping to endpoints is not shown in the current example, see chapter 9.2.1 for more information.

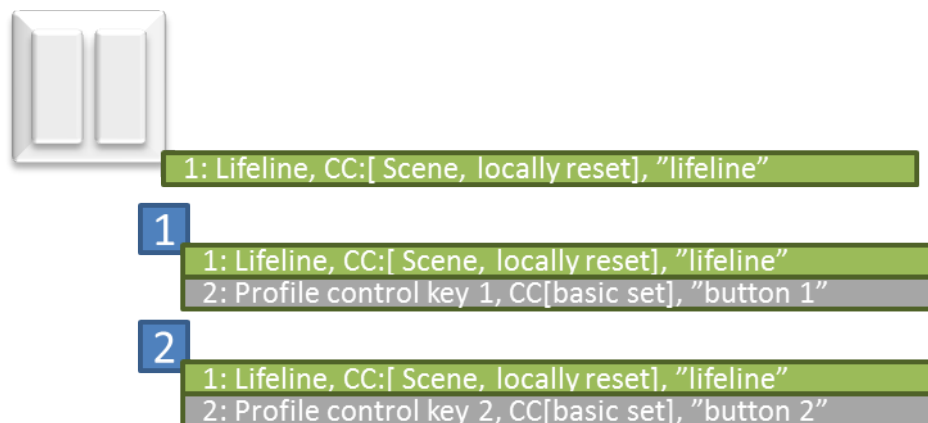


Figure 8. Extended with Two Endpoints and Remove Root group 2

Table 3. Add Endpoints to a Wall Controller

```

CMD_CLASS_GRP agiTableLifeline[] =
{
    {COMMAND_CLASS_CENTRAL_SCENE, CENTRAL_SCENE_NOTIFICATION},
    {COMMAND_CLASS_DEVICE_RESET_LOCALLY, DEVICE_RESET_LOCALLY_NOTIFICATION}
};

AGI_GROUP agiTableEndpoint1Groups[] =
{
    ASSOCIATION_GROUP_INFO_REPORT_PROFILE_CONTROL,
    ASSOCIATION_GROUP_INFO_REPORT_PROFILE_CONTROL_KEY01,
    {COMMAND_CLASS_BASIC, BASIC_SET}, "Button 1"
};

AGI_GROUP agiTableEndpoint2Groups[] =
{
    ASSOCIATION_GROUP_INFO_REPORT_PROFILE_CONTROL,
    ASSOCIATION_GROUP_INFO_REPORT_PROFILE_CONTROL_KEY02,
    {COMMAND_CLASS_BASIC, BASIC_SET}, "Button 2"
};

void AppStateManager(EVENT_APP event)
{
    switch (currentState) {
        case STATE_APP_STARTUP:
            if (EVENT_APP_INIT == event) {
                AGI_Init();
            }
    }
}

```

```

/*Root device configuration*/
CC_AGI_LifeLineGroupSetup(
    agiTableLifeLine,
    sizeof_array(agitableLifeLine),
    ENDPOINT_ROOT);

/*Endpoint configuration*/
CC_AGI_LifeLineGroupSetup(
    agiTableLifeLine,
    sizeof_array(agitableLifeLine),
    ENDPOINT_1);
AGI_ResourceGroupSetup(
    agiTableEndpoint1Groups,
    sizeof_array(agitableEndpoint1Groups),
    ENDPOINT_1);
CC_AGI_LifeLineGroupSetup(
    agiTableLifeLine,
    sizeof_array(agitableLifeLine),
    ENDPOINT_2);
AGI_ResourceGroupSetup(
    agiTableEndpoint2Groups,
    sizeof_array(agitableEndpoint2Groups),
    ENDPOINT_2);
:

```

### 9.1.2 Using AGI

The AGI module handles the reading of the destination node list from the Association module. After the configuration of the AGI module, the application does not access the AGI module again. The Command Classes access the AGI module when calling the *ReqNodeList()* function for an unsolicited event job.

```

TRANSMIT_OPTIONS_TYPE_EX * ReqNodeList(
    AGI_PROFILE const * const pProfile,
    CMD_CLASS_GRP* pCurrentCmdGrp,
    uint8_t sourceEndpoint);

```

## 9.2 Association Module

The Association module is a small database handling all associations. The Association and Multi-Channel Associations Command Class modules are interfacing with the Association module for adding or removing associations. The database is stored in NVM. The AGI module handles the reading of the node list from the database.

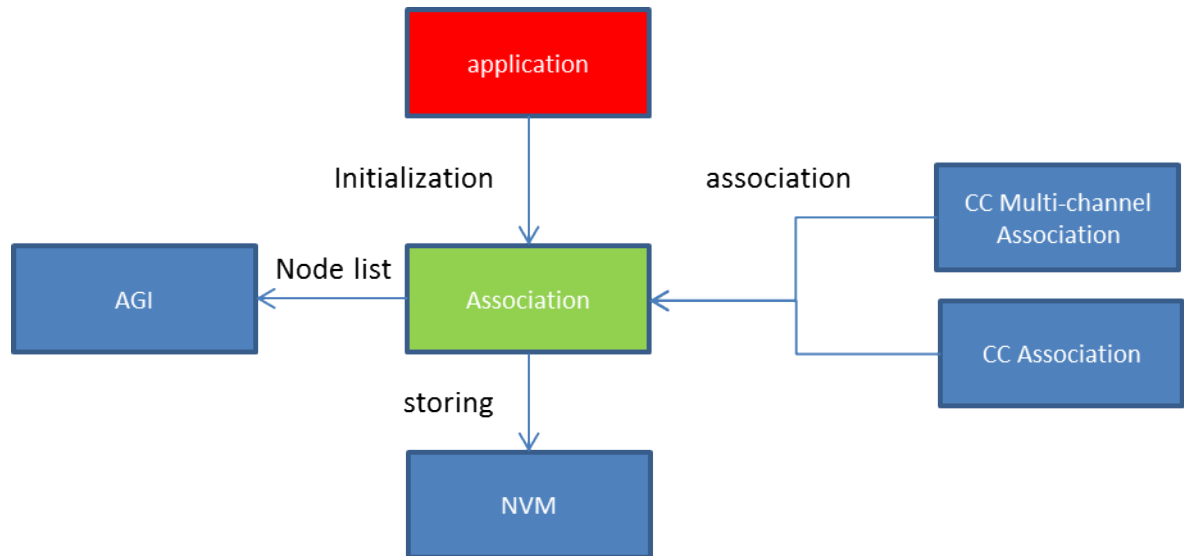


Figure 9. Association Behavior Diagram

### 9.2.1 Initialization

The initialization of the Association module is done in the `SetDefaultConfiguration` and `LoadConfiguration` functions and depends on support for endpoints.

The number of associations is calculated from the following definitions:

- Number of associations in a group: `MAX_ASSOCIATION_IN_GROUP`
- Number of association groups: `MAX_ASSOCIATION_GROUPS`
- Number of individual endpoints: `NUMBER_OF_INDIVIDUAL_ENDPOINTS`
- Number of aggregated endpoints: `NUMBER_OF_AGGREGATED_ENDPOINTS`
- The total number of endpoints is sum of individual and aggregated endpoints in the device: `NUMBER_OF_ENDPOINTS`

Definitions are configured in the `config_app.h` file and used in `association_plus.h`.

When no endpoint is implemented, the application must call the `AssociationInit()` function. The parameter “`forceClearMem`” is used for clearing the association NVM data, and “`pFS`” is a pointer to the application file system in NVM.

```
void AssociationInit(bool forceClearMem, nvm3_Handle_t* pFS);
```

When the application implement endpoints, the application must call the `AssociationInitEndpointSupport()` function. The function takes the following parameters:

- “`forceClearMem`” is used for clearing the association NVM data.
- “`pMapping`” is used for backwards compatibility with non-Multi Channel devices. The root group mapping is used to configure the Root Device to advertise association groups on behalf of endpoints.
- “`nbrGrp`” is the number of groups in `pMapping` list.
- “`pFS`” is a pointer to the application file system in NVM.

```
void AssociationInitEndpointSupport(
    bool forceClearMem,
    ASSOCIATION_ROOT_GROUP_MAPPING* pMapping,
    uint8_t nbrGrp,
    nvm3_Handle_t* pFS);
```

### 9.2.1.1 Example 3: How to Use Group Mapping

In this example, the Wall Controller Root Device has 2 association groups and maps them to its endpoints; see previous example in 9.1.1.2. The goal is to map associations from the [Root Device, group 2] to the [endpoint 1, group 2] and from the [Root Device, group 3] to the [endpoint 2, group 2]. More information can be found in [6].

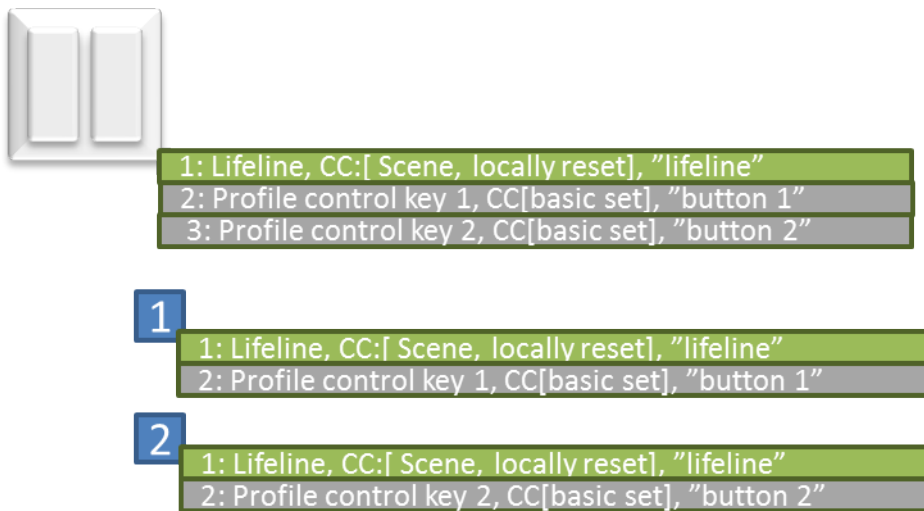


Figure 10. Wall Controller with Root Device Group Mapping

Table 4. AGI Root groups 2 and 3 (Mapped to Endpoint 1 and 2) Setup

```
AGI_GROUP agiTableRootDeviceGroups[] =
{
    {
        ASSOCIATION_GROUP_INFO_REPORT_PROFILE_CONTROL,
        ASSOCIATION_GROUP_INFO_REPORT_PROFILE_CONTROL_KEY01,
        {COMMAND_CLASS_BASIC, BASIC_SET}, "Button 1"
    },
    {
        ASSOCIATION_GROUP_INFO_REPORT_PROFILE_CONTROL,
        ASSOCIATION_GROUP_INFO_REPORT_PROFILE_CONTROL_KEY02,
        {COMMAND_CLASS_BASIC, BASIC_SET}, "Button 2"
    }
};

/*root grp, endpoint, endpoint group*/
ASSOCIATION_ROOT_GROUP_MAPPING rootGroupMapping[] = {
    {ASS_GRP_ID_2, ENDPOINT_1, ASS_GRP_ID_2},
    {ASS_GRP_ID_3, ENDPOINT_2, ASS_GRP_ID_2}
};

void AppStateManager(EVENT_APP event)
```



```

{
    switch (currentState) {
        case STATE_APP_STARTUP:
            if (EVENT_APP_INIT == event) {
                AGI_Init();

                /*Root device configuration*/
                AGI_ResourceGroupSetup(
                    agiTableRootDeviceGroups,
                    sizeof_array(agitableRootDeviceGroups),
                    ENDPOINT_ROOT);
            }
    }

    void SetDefaultConfiguration(void)
    {
        :
        AssociationInitEndpointSupport(TRUE,
                                        rootGroupMapping,
                                        sizeof_array(rootGroupMapping));
        :
    }

    bool LoadConfiguration(void)
    {
        :
        AssociationInitEndpointSupport(FALSE,
                                        rootGroupMapping,
                                        sizeof_array(rootGroupMapping));
        :
    }
}

```

### 9.3 Interfacing Firmware Update Module “ota\_util”

The Ota\_util module handles OTA firmware update. It is interfacing to Firmware Update Meta Data CC and delivers an interface to the application to manage the process.

Ota\_util API:

```

BYTE
OtaInit(
    BOOL (CODE *pOtaStart)(WORD fwId, WORD CRC),
    VOID_CALLBACKFUNC(pOtaExtWrite)( BYTE *pData, BYTE dataLen),
    VOID_CALLBACKFUNC(pOtaFinish)(BYTE val));

```

Input parameters pOtaStart and pOtaFinish is used to inform the application of the status of firmware update and give the application the capability to control the start of firmware update. It is possible to not call OtaInit and the process runs without the application with standard parameters for txOption. Input parameter pOtaExtWrite is used to update host firmware.

[3] gives a detailed description on how to interface to the “ota\_util” module.

## 9.4 Peripheral Drivers

Several peripheral drivers are available (EMDRV and EMLIB) and must be linked to the application before the hardware device in question can be accessed. EMDRV exist on top of the lower level EMLIB. Source code is also available for customization.

The Z-Wave 700 SDK is event-driven that requires an event-driven design to access the hardware device. Calls are already implemented for handling GPIOs (see Section 9.4.1). Refer to links below for further details.

Software Documentation (e.g., EMDRV and EMLIB)

[https://siliconlabs.github.io/Gecko\\_SDK\\_Doc/efr32fg13/html/index.html](https://siliconlabs.github.io/Gecko_SDK_Doc/efr32fg13/html/index.html)

Technical Resource Search (Application Notes)

[https://www.silabs.com/support/resources.ct-application-notes.ct-example-code.p-microcontrollers\\_32-bit-mcus?](https://www.silabs.com/support/resources.ct-application-notes.ct-example-code.p-microcontrollers_32-bit-mcus?)

32-bit Peripheral Examples (EMLIB)

[https://github.com/SiliconLabs/peripheral\\_examples](https://github.com/SiliconLabs/peripheral_examples)

### 9.4.1 GPIO

For the Wireless Starter Kit Mainboard (BRD4001A) with a ZGM130S Radio Board (BRD4202A) and a Buttons and LEDs EXP Board (BRD8029A), the file *board.c* provides a high-level support for buttons and LEDs (Note: *board.c* does not currently make use of the EFR32 Flex Gecko board support packages).

The mapping of buttons and LEDs to actual GPIO ports and pins are defined in the two header files: *extension\_board\_4001a.h* and *radio\_board\_zgm130s.h* included with *board.h*.

The board should be initialized with *Board\_Init()* from *ApplicationInit()*.

```
ZW_APPLICATION_STATUS ApplicationInit(EResetReason_t eResetReason)
{
    :
    Board_Init();
    :
}
```

To subscribe to button events from a specific button, simply call *Board\_EnableButton()* from the application thread.

```
void Board_EnableButton(button_id_t btn);
```

The application will then receive events of type *BUTTON\_EVENT* (*<btn\_id>\_DOWN*, *<btn\_id>\_UP*, *<btn\_id>\_SHORT\_PRESS*, *<btn\_id>\_HOLD*, *<btn\_id>\_LONG\_PRESS*).

LEDs are controlled with the *Board\_SetLed()* function that simply takes an *LED\_ON* or *LED\_OFF* value as parameter:

```
void Board_SetLed(led_id_t led, led_state_t state);
```

#### 9.4.1.1 GPIO Port Usage in Serial API

The GPIO port usage in the serial API applications for EFR32ZG14 and ZGM130S respectively are as follows:

GPIO	EFR32ZG14 Usage
PA0	UART/VCOM TX
PA1	UART/VCOM RX
PB11	<i>For future use</i>
PB12	<i>For future use</i>
PB13	<i>For future use</i>
PB14	SAW Filter Select 1
PB15	SAW Filter Select 2
PC10	<i>For future use</i>
PC11	<i>For future use</i>
PD13	<i>For future use</i>
PD14	VCOM Enable
PD15	<i>For future use</i>
PF0	Serial Wire Debug Clock
PF1	Serial Wire Debug Data I/O
PF2	Serial Wire Debug Output
PF3	<i>For future use</i>

GPIO	ZGM130S Usage
PA0	UART0/VCOM TX
PA1	UART0/VCOM RX
PA2	UART0/VCOM CTS
PA3	UART0/VCOM RTS
PA4	<i>For future use</i>
PA5	VCOM Enable
PB11	<i>For future use</i>

PB12	<i>For future use</i>
PB13	<i>For future use</i>
<b>PB14</b>	<b>SAW Filter Select 1</b>
<b>PB15</b>	<b>SAW Filter Select 2</b>
PC6	<i>For future use</i>
PC7	<i>For future use</i>
PC8	<i>For future use</i>
PC9	<i>For future use</i>
PC10	<i>For future use</i>
PC11	<i>For future use</i>
PD9	<i>For future use</i>
PD10	<i>For future use</i>
PD11	<i>For future use</i>
PD12	<i>For future use</i>
PD13	<i>For future use</i>
PD14	<i>For future use</i>
PD15	<i>For future use</i>
<b>PF0</b>	<b>Serial Wire Debug Clock</b>
<b>PF1</b>	<b>Serial Wire Debug Data I/O</b>
<b>PF2</b>	<b>Serial Wire Debug Output</b>
PF3	<i>For future use</i>
PF4	<i>For future use</i>
PF5	<i>For future use</i>
PF6	<i>For future use</i>
PF7	<i>For future use</i>

### 9.4.2 UART Driver

The UART driver uses the UART RX interrupt to wake up the application when it has collected enough relevant data. This is done as follows:

1. Define a new application event, e.g., `EAPPLICATIONEVENT_SERIALDATARX` in the enum `EApplicationEvent`.
2. Install an event handler (this is a callback) in static const `EventDistributorEventHandler` `g_aEventHandlerTable`.

```

Trigger the event from the ISR
Void USART0_RX_IRQHandler() {
... Collect data ...

    If(enough_data) {
        xTaskNotifyFromISR(g_AppTaskHandle,
            1<< EAPPLICATIONEVENT_SERIALDATARX,
            eSetBits,
            NULL);
    }
}

```

3. Enable the UART RX IRQ (for more information, read the standard EMLIB documentation such as [21]).

The event handler is called in the application thread context, which is good because this ensures thread safety in the application. It is not recommended to add more threads to the application.

### 9.4.3 ADC Driver

The Z-Wave Application Framework contains an API for measuring the supply voltage using the Analog-to-Digital Converter (ADC) of the ZGM130S.

Applications can use this API to get the current supply voltage level. The typical use case is for obtaining the battery status in battery operated devices.

The API consists of the following functions:

Function:	Description:
<code>void ZAF_ADC_Enable(void)</code>	Initialize and enables the ADC
<code>void ZAF_ADC_Disable(void)</code>	Disables the ADC
<code>uint32_t ZAF_ADC_Measure_VSupply(void)</code>	Returns the supply voltage in millivolts

API function prototypes are defined in the following header file, which must be included from the Application:

```
#include "ZAF_adc.h"
```

Typical usage example:

```

ZAF_ADC_Enable(); // Enable the ADC

VBATT_mV = ZAF_ADC_Measure_VSupply(); // Read the battery voltage

```

```
ZAF_ADC_Disable(); // All done - disable the ADC
```

Further usage examples can be found in the certified Z-Wave applications DoorLockKeyPad and SensorPIR.

## 9.5 Event Distributor

The objectives of the Event Distributor are to receive events on several FIFO message queues, wake up the application task whenever a message is available, and call the event handler associated with each queue.

### 9.5.1 Event Loop

A Z-Wave application task is basically an endless event loop calling *EventDistributorDistribute()*.

```
ApplicationTask(SApplicationHandles* pAppHandles)
{
    /* Task initialization */
    :
    /* Endless event loop */
    for (;;)
    {
        EventDistributorDistribute(&g_EventDistributor, 10, 0);
    }
}
```

The events to the application task arrives on several queues. If none of the queues has messages to read, the application task will sleep for a number of milliseconds (10 ms in the example above). Whenever a message arrives on a queue, the application task will wake up and dispatch the message to one of the configured functions.

The first parameter of type *SEventDistributor* contains configuration data for the event distributor.

```
uint32_t EventDistributorDistribute(const SEventDistributor* pThis,
                                   uint32_t iEventWait,
                                   uint32_t NotificationClearMask);
```

The *SEventDistributor* variable used with *EventDistributorDistribute()* must first be initialized with *EventDistributorConfig()*:

```
EEventDistributorStatus EventDistributorConfig(
    SEventDistributor* pThis,
    uint8_t iEventHandlerTableSize,
    const EventDistributorEventHandler* pEventHandlerTable,
    void(*pNoEvent)(void) );
```

The *pEventHandlerTable* is an array of *EventDistributorEventHandler*, which is simply a function pointer to the event handler functions.

```
typedef void (*EventDistributorEventHandler)(void);
```

Note: The parameter *pNoEvent*, if non-null, will be called every time *EventDistributorDistribute()* wakes up and finds that there are no messages to process.

Each message queue is assigned a *notification bit number*. The order of event handler functions in *pEventHandlerTable* must correspond to those bit numbers; e.g., when a message arrives on the queue with notification bit number 2, the event handler function at array index 2 in *pEventHandlerTable* will be called.

The bit numbers are conveniently defined with the *EApplicationEvent* enumeration:

```
typedef enum
{
    EAPPLICATIONEVENT_TIMER = 0,
    EAPPLICATIONEVENT_ZWRX,
    EAPPLICATIONEVENT_ZWCOMMANDSTATUS,
    EAPPLICATIONEVENT_APP
} EApplicationEvent;
```

The event handler table to use with *EventDistributorConfig()* can then be defined like this:

```
static const EventDistributorEventHandler m_aEventHandlerTable[] =
{
    AppTimerNotificationHandler,
    EventHandlerZWRx,
    EventHandlerZwCommandStatus,
    EventHandlerApp
};
```

An implementation of *AppTimerNotificationHandler()* is provided by the framework, the other remaining functions must be implemented by the application developer.

### 9.5.2 Event Queues

The queue creation (and notification bit assignment) for message queues receiving the Z-Wave packages and Z-Wave command results are specified in *ApplicationInit()* with *ZW\_ApplicationRegisterTask()*. Application timer events are not placed on a queue, but are sent to the application using the notification interface and must therefore be assigned a notification bit number by calling *AppTimerInit()*:

```
ZW_APPLICATION_STATUS ApplicationInit(EResetReason_t eResetReason)
{
    :
    AppTimerInit(EAPPLICATIONEVENT_TIMER, NULL);
    :
    ZW_ApplicationRegisterTask(ApplicationTask,
                              (1536 / 4),
                              EAPPLICATIONEVENT_ZWRX,
                              EAPPLICATIONEVENT_ZWCOMMANDSTATUS,
                              &ProtocolConfig);
    :
}
```

The application message queue must be created with the FreeRTOS function *xQueueCreateStatic()*. First, a storage space for the queue must be defined (in this example, we are allocating a space for 5 application events on the queue). After the queue has been created, it must be assigned the application notification bit with *QueueNotifyingInit()*. Finally, the *ZAF\_EventHelper* module must be configured to use the application queue:

```
static EVENT_APP eventQueueStorage[5];
static StaticQueue_t m_AppEventQueueObject;
static QueueHandle_t m_AppEventQueueHandle;
static SQueueNotifying m_AppEventNotifyingQueue;
static TaskHandle_t m_AppTaskHandle;

void
ApplicationTask(SApplicationHandles* pAppHandles)
{
    m_AppTaskHandle = xTaskGetCurrentTaskHandle();
    :
    m_AppEventQueueHandle = xQueueCreateStatic(sizeof_array(eventQueueStorage),
                                                sizeof(eventQueueStorage[0]),
                                                (uint8_t*)eventQueueStorage,
                                                &m_AppEventQueueObject);

    QueueNotifyingInit(&m_AppEventNotifyingQueue,
                      m_AppEventQueueHandle,
                      m_AppTaskHandle,
                      EAPPLICATIONEVENT_APP);

    ZAF_EventHelperInit(&m_AppEventNotifyingQueue);
    :
}
```

The *ZAF\_EventHelper* module provides a simple way of placing events on the application event queue:

**File zaf\_event\_helper.h:**

```
void ZAF_EventHelperInit(SQueueNotifying * pQueueNotifyingHandle);
bool ZAF_EventHelperEventEnqueue(const uint8_t event);
bool ZAF_EventHelperEventEnqueueFromISR(const uint8_t event);
```

### 9.5.3 Event Handler

Each of the event handlers in the *EventDistributorEventHandler* table used when calling *EventDistributorConfig()* is simply called when one or more messages are available on its message queue. The event handler must receive and process all available messages from the queue. For example, the application event handler will typically be implemented as follows, where all events are simply forwarded to the application state manager function:



```
static void EventHandlerApp(void)
{
    uint8_t event;
    while (xQueueReceive(m_AppEventQueue, &event, 0) == pdTRUE)
    {
        AppStateManager((EVENT_APP)event);
    }
}
```

### 9.5.4 Job Event Queue

Applications often have the need to temporarily queue up events that first should be processed when the active job is finished. For this reason, the *ZAF\_JobHelper* module provides its own job event queue that is not handled by the Event Distributor. The application must explicitly enqueue and dequeue events on the job queue as needed. First, the application must call *ZAF\_JobHelperInit()* to initialize the job event queue to hold *JOB\_QUEUE\_BUFFER\_SIZE* events. The *ZAF\_JobHelperJobEnqueue()* and *ZAF\_JobHelperJobDequeue()* can then be used to put and get events on the queue.

**File *zaf\_job\_helper.h*:**

```
#define JOB_QUEUE_BUFFER_SIZE 3

void ZAF_JobHelperInit(void);
bool ZAF_JobHelperJobEnqueue(uint8_t event);
bool ZAF_JobHelperJobDequeue(uint8_t * pEvent);
```

### 9.5.5 Simple Event Handling

In the simplest form, only the application event queue will be used, for example, to execute a single command when a user presses a button. The file *board.c* uses the *ZAF\_EventHelper* module to send button events to the application queue which will result in the *EventHandlerApp()* function activating *AppStateManager()* with the button event.

1. In learn mode the user presses key01, which changes the state to *STATE\_APP\_STARTUP*:

```

void AppStateManager(EVENT_APP event)
{
    :
    switch(currentState) {
        :
        case STATE_APP_LEARN_MODE:
            :
            if ((BTN_EVENT_SHORT_PRESS(APP_BUTTON_LEARN_RESET) == (BUTTON_EVENT)event ||
                (EVENT_SYSTEM_LEARNMODE_STOP == (EVENT_SYSTEM)event)) {
                :
                ChangeState(STATE_APP_STARTUP);
                :
            }
            :
        }
    }
}

```

When learn process is completed, *EventHandlerZwCommandStatus* will be triggered by protocol with status *EZWAVECOMMANDSTATUS\_LEARN\_MODE\_STATUS*, which will trigger *LearnCompleted()*, from where *ZAF\_EventHelperEventEnqueue((EVENT\_APP) EVENT\_SYSTEM\_LEARNMODE\_FINISHED)* is called:

```

static void LearnCompleted(void)
{
    ...
    ZAF_EventHelperEventEnqueue((EVENT_APP) EVENT_SYSTEM_LEARNMODE_FINISHED);
    Transport_OnLearnCompleted(bNodeID);
}

```

2. In state *STATE\_APP\_STARTUP*, the wanted functionality is executed and the state changes back to the idle state *STATE\_APP\_IDLE*.

```

:
case STATE_APP_STARTUP:
    if (EVENT_APP_INIT == event) {
        :
        ChangeState(STATE_APP_IDLE);
    }
    :

```

### 9.5.6 Multiple Event Jobs Handling

It is possible to enqueue more jobs during the execution with the *ZAF\_JobHelper* module.

The example below illustrates how the job queue is used to expand a button press into multiple actions (send a Basic Set followed by send a Notification) to be performed in the state *STATE\_APP\_TRANSMIT\_DATA*.

```

case STATE_APP_IDLE:
:
if ((BTN_EVENT_DOWN(PIR_EVENT_BTN) == (BUTTON_EVENT)event) ||
    (BTN_EVENT_HOLD(PIR_EVENT_BTN) == (BUTTON_EVENT)event))
{
:
ChangeState(STATE_APP_TRANSMIT_DATA);

if (false == ZAF_EventHelperEventEnqueue(EVENT_APP_NEXT_EVENT_JOB))
{
    DPRINT("\r\n** EVENT_APP_NEXT_EVENT_JOB fail\r\n");
}
/*Add event's on job-queue*/
ZAF_JobHelperJobEnqueue(EVENT_APP_BASIC_START_JOB);
ZAF_JobHelperJobEnqueue(EVENT_APP_NOTIFICATION_START_JOB);
ZAF_JobHelperJobEnqueue(EVENT_APP_START_TIMER_EVENTJOB_STOP);
}

```

In state *STATE\_APP\_TRANSMIT\_DATA*, shown next, the event *EVENT\_APP\_NEXT\_EVENT\_JOB* starts the job by fetching the first job event from the job event queue.

Each *send*-function is provided with a pointer to the call-back function *ZCB\_JobStatus()* that will be called by the framework when the transmission has completed. *ZCB\_JobStatus()* will simply place a *EVENT\_APP\_NEXT\_EVENT\_JOB* event on the application event queue to trigger the processing of the next job event.

```

void ZCB_JobStatus(TRANSMISSION_RESULT * pTransmissionResult)
{
    if (TRANSMISSION_RESULT_FINISHED == pTransmissionResult->isFinished)
    {
        ZAF_EventHelperEventEnqueue(EVENT_APP_NEXT_EVENT_JOB);
    }
}

```

## 9.6 Power Manager

The Z-Wave chip provides several low energy modes (EM). Each energy mode manages whether the CPU and its various peripherals are available. The energy modes range from EM0 Active to EM4 Shutoff. EM0 Active mode provides the highest number of features, enabling the CPU, Radio, and peripherals with the highest clock frequency. EM4 Shutoff Mode provides the lowest power state, allowing the chip to return to EM0 Active on a wake-up condition.

To achieve the longest possible battery life, it is essential that Z-Wave applications on battery powered devices reduce the time spent in the higher energy modes as much as possible.

The Z-Wave Power Manager owned by the Z-Wave protocol thread controls what energy mode the RTOS should go to when idle. It uses the concept of *Power Locks* where regions of code can lock the chip from entering a specific energy mode. The Power Manager keeps track of all power locks and ensures that the chip does not at any time enter a power mode lower than what is currently requested.

To interact with the Power Manager from an application, use the Power Management API in *ZAF\_PM\_Wrapper.h*. To use it, first initialize the interface with *API\_IF\_init()*, and then register a power lock with *ZAF\_PM\_Register()*.

```
void API_IF_init(SApplicationHandles* pAppHandles);  
void ZAF_PM_Register(SPowerLock_t* handle, pm_type_t type);
```

Use the power lock type *pm\_type\_t* to tell the Power Manager if the power lock should “protect” code that need access to the radio (*PM\_TYPE\_RADIO*: do not enter EM2/EM3/EM4) or just some peripherals (*PM\_TYPE\_PERIPHERAL*: don’t enter EM3/EM4).

After the power lock has been registered, *ZAF\_PM\_StayAwake()* and *ZAF\_PM\_Cancel()* can be used to wrap the code that needs access to the radio or peripherals:

```
void ZAF_PM_StayAwake(SPowerLock_t* handle, unsigned int msec);  
void ZAF_PM_Cancel(SPowerLock_t* handle);
```

If the *msec* parameter to *ZAF\_PM\_StayAwake()* is non-zero, the power lock will automatically be cancelled after the specified time (in that case, a call to *ZAF\_PM\_Cancel()* is not required).

```
static SPowerLock_t m_RadioPowerLock;  
  
static void  
ApplicationTask(SApplicationHandles* pAppHandles)  
{  
    API_IF_init(pAppHandles);  
  
    ZAF_PM_Register(&m_RadioPowerLock, PM_TYPE_RADIO);  
    :  
}  
  
void SomeFunction(void)  
{  
    ZAF_PM_StayAwake(&m_RadioPowerLock, 0);  
    :  
    /* Do something where the radio module is required */  
    :  
    ZAF_PM_Cancel(&m_RadioPowerLock);  
    :  
}
```

Several callbacks from the protocol to the framework supported enabling execution of specific code as the last thing before entering sleep mode. Up to three callbacks are available. For details refer to function *ZAF\_PM\_SetPowerDownCallback()* in *ZAF\_PM\_Wrapper.h*.

The applications *DoorLockKeyPad* (Listening Sleeping End Device) and *SensorPIR* (Reporting Sleeping End Device) both use power locks. *SensorPIR* goes all the way to EM4 when idle, but since a Listening Sleeping End Device must wake up every 250 ms or 1000 ms, the *DoorLockKeyPad* application only sleeps in EM2 to achieve a fast wakeup time.

## 9.7 Application Timers

The AppTimer module provides an application interface for software timers.

**File:** AppTimer.h

```
void AppTimerInit(uint8_t iTaskNotificationBitNumber, TaskHandle_t ReceiverTask);
void AppTimerSetReceiverTask(TaskHandle_t ReceiverTask);
bool AppTimerRegister(SSwTimer* pTimer, bool bAutoReload, void(*pCallback)(SSwTimer*
pTimer) );
void AppTimerNotificationHandler(void);
```

All software timers are essentially FreeRTOS timers running in the high priority FreeRTOS timer task. Any timer callbacks are normally executed in the context of the timer task. Using the *AppTimer* module, you can ensure that timer callback functions are executed in the context of the application task.

**Note:** If a timer expires while, e.g., a battery-operated device is deep sleeping in energy mode EM4 Shutoff, the device will wake up, but the timer callback function will **not** be executed, since the device will be going through a full startup initialization.

To start using application timers, you need a *SSwTimer* instance and you need to initialize the *AppTimer* module. That is usually done in *ApplicationInit()*:

```
#include <AppTimer.h>

static SSwTimer myAppTimer;

ZW_APPLICATION_STATUS ApplicationInit(EResetReason_t eResetReason)
{
    AppTimerInit(EAPPLICATIONEVENT_TIMER, NULL);
}
```

See Section 9.5.1 for a description of the *EAPPLICATIONEVENT\_TIMER* notification bit number and the framework function *AppTimerNotificationHandler()*.

In the *ApplicationTask()* function, you need to register the handle of the application task with the *AppTimer* module and also register all your *SSwTimers* (it is possible to register up to eight application timers):

```
void ApplicationTask(SApplicationHandles* pAppHandles)
{
    m_AppTaskHandle = xTaskGetCurrentTaskHandle();

    AppTimerSetReceiverTask(m_AppTaskHandle);
    AppTimerRegister(&myAppTimer, false, ZCB_MyAppTimerCallback);
}
```

The timeout callback could be implemented like this:

```
void ZCB_MyAppTimerCallback(SSwTimer *pTimer)
{
    UNUSED(pTimer);
    ZAF_EventHelperEventEnqueue(EVENT_APP_MY_TIMER_TIMEOUT);
}
```

To start and stop an application timer, simply use the functions from the SwTimer module (all timeout values in milliseconds):

**File: SwTimer.h**

```
ESwTimerStatus TimerStart(SSwTimer* pTimer, uint32_t iTimeout);
ESwTimerStatus TimerStartFromISR(SSwTimer* pTimer, uint32_t iTimeout);
ESwTimerStatus TimerRestart(SSwTimer* pTimer);
ESwTimerStatus TimerRestartFromISR(SSwTimer* pTimer);
ESwTimerStatus TimerStop(SSwTimer* pTimer);
ESwTimerStatus TimerStopFromISR(SSwTimer* pTimer);
bool TimerIsActive(SSwTimer* pTimer);
```

When one or more application timers expire, the framework function *AppTimerNotificationHandler()* is called, which in turn calls the timer callback function for each of the timers that have expired.

If an *autoloading* timer (i.e., restarts automatically) is configured with a very small timeout value, it is possible it can expire multiple times before *AppTimerNotificationHandler()* is called. In that case, the timeout events will *not* be queued; *AppTimerNotificationHandler()* will only be called a single time.

Be careful when using timers inside Interrupt Service Routines (ISR). As *TimerStartISR* uses *xTimerChangePeriodFromISR* (freeRTOS) <https://www.freertos.org/FreeRTOS-timers-xTimerChangePeriodFromISR.html>, it is not advisable to start more than ONE timer from ISR with *TimerStartISR*. Finally, use only the dedicated ISR functions in the ISR.

## 10 Firmware Update Images and Bootloader

The purpose of this section is to describe how to generate and manage firmware update images. The ZW700 SDK comes with three bootloader images. One is the OTW image for the FG14 module. This bootloader is only meant for FG14 devices, which runs the SerialAPI.

The other two bootloaders are the OTA bootloader for the ZGM130S module and an OTW bootloader for the ZGM130S. The OTA bootloader is needed for all ZW700 based devices, which implement firmware updates; the OTW bootloader is for devices, which update firmware using the serial port from another host controller. The OTA bootloader is triggered when an image has been transferred over the air using the FIRMWARE\_UPDATE command class. The transferred image must be an image in Gecko Boot Loader(GBL) format. The bootloaders provided in the SDK require the GBL image to be signed.

Three steps are needed for performing an OTA update:

1. The OTA bootloader must be flashed.
2. The Signing keys and optionally an encryption key must be flashed.
3. A signed image must be transferred using the firmware update command class.

The OTA key locations are as follows depending on SoC:

- For ZGM13: protocol\z-wave\BootLoader\sample-keys
- For EFR32ZG14P: protocol\z-wave\BootLoader\ZG14\_keys

Further information about the bootloaders can be found in [17].

### 10.1 Generate GLB Files

To generate the GBL files needed for the OTA update, a signing keypair must first be created. It is the intention that a vendor will keep the signing keypair for the lifetime of the product. These keys are used to sign all firmware versions for the whole lifetime of the product. An encryption key must also be created, this key is intended for encrypting the GBL file. Encryption makes it harder for a bootlegger to copy the product.

The signing keys can be created by using Simplicity Commanders command line interface.

```
commander.exe gbl keygen --type ecc-p256 -o vendor_sign.key
```

This step will create 3 files:

1. *vendor\_sign.key* - This is the private key and must be kept safely by the product manufacturer.
2. *vendor\_sign.key.pub* - This is the public key.
3. *vendor\_sign.key-tokens.txt* - This is the public key in another format which can be programmed into the device at manufacturing using simplicity commander.

A vendor may choose to have a key pair like this for all his products, or one for each product type.

An encryption key can be generated as follows:

```
commander.exe gbl keygen --type aes-ccm -o vendor_encrypt.key
```

Once the two keys have been obtained, a GBL file may be produced as follows:

```
commander.exe gbl create appname.gbl --app appname.hex --sign  
vendor_sign.key --encrypt vendor_encrypt.key --compress lz4
```

This should be done each time a new firmware is produced.

## 10.2 Flashing the Boot Loader and App

It is possible to flash the boot loader including the public signing key and the encryption key using commander.exe. The list below shows args to commander.exe for a board having SN 440049475 as an example:

1. Erase Flash args:device masserase -s 440049475 -d Cortex-M4
2. Reset args:device reset -s 440049475 -d Cortex-M4
3. Erase Bootloader args:device pageerase --region @bootloader -s 440049475 -d Cortex-M4
4. Erase Lockbits args:device pageerase --region @lockbits -s 440049475 -d Cortex-M4
5. Program Bootloader args:flash C:\dk2\Apps458\BootLoader\_7.11.0\_458\OTA-bootloader-fg13-combined.s37 -s 440049475 -d Cortex-M4
6. Program Keys args:flash --tokengroup znet --tokenfile  
C:\dk2\Apps458\BootLoader\_7.11.0\_458\sample\_encrypt.key --tokenfile  
C:\dk2\Apps458\BootLoader\_7.11.0\_458\sample\_sign.key-tokens.txt -s 440049475 -d Cortex-M4
7. Erase Flash args:device masserase -s 440049475 -d Cortex-M4
8. Reset args:device reset -s 440049475 -d Cortex-M4
9. Program Flash args:flash  
"C:\dk2\Apps458\PowerStrip\ZW\_PowerStrip\_7.11.0\_458\_ZGM130S\_REGION\_IN.hex" --address 0x0 --  
serialno 440049475 --device Cortex-M4
10. Reset args:device reset -s 440049475 -d Cortex-M4

Minor modifications are needed in steps 3 and 4 if the commands are run on a Windows Powershell:

3. Erase Bootloader args:device pageerase --region "@bootloader" -s 440049475 -d Cortex-M4
4. Erase Lockbits args:device pageerase --region "@lockbits" -s 440049475 -d Cortex-M4

Note that the bootloader and keys are not erased by a normal mass erase.



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