UG491: Zigbee Application Framework Developer's Guide for SDK 7.0 and Higher

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The Zigbee Application Framework is a body of embedded C code that can be configured by project configuration tools to implement any Zigbee Cluster Library (ZCL) application. This guide covers the structure and usage of the Zigbee Application Framework in SDK 7.x.

KEY POINTS

- Provides a reference for all aspects of the Zigbee Application Framework, including callbacks, the API, and the Command Line Interface (CLI).
- Offers guidelines for designing an application with Project Configuration tools.
- Discusses how to extend the ZCL.

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1 Introduction

The Zigbee Application Framework (also known as the ZCL Application Framework) is a body of embedded C code that can be configured by the Project Configuration Tools to implement any Zigbee Cluster Library (ZCL) application. Beginning with SDK version 7.0.0, Zigbee applications are configured through a component-based architecture using the Simplicity Studio 5 Project Configurator rather than a plugin-based architecture using the legacy AppBuilder tool. This guide covers the structure and usage of the Zigbee Application Framework.

This document assumes that you are familiar with using Simplicity Studio 5's project configuration tools to create and configure Zigbee projects. For more information, see:

- Simplicity Studio 5 User's Guide
- *QSG180: Zigbee EmberZNet Quick-Start Guide for SDK 7.x and Higher*
- *AN1325: Zigbee Cluster Configurator User's Guide*

If you have been using earlier versions of the Zigbee EmberZNet SDK, see *AN1301: Transitioning from Zigbee EmberZNet SDK 6.x to SDK 7.x* for a detailed description of differences between the two versions.

2 Application Framework Architecture

The Zigbee Application Framework sits on top of the Zigbee stack, consumes the stack “handler” interfaces, and exposes its own more highly abstracted and application-specific interface to the developer.

One of the main features of the Zigbee Application Framework is its ability to separate user-created and Silicon Labs-created code. While Silicon Labs provides all the source code for the Zigbee Application Framework, user-created code should live outside the framework and should interact with the framework through the Zigbee Application Framework API exposed by the framework utilities and callbacks. The block diagram in the following figure shows a high-level overview of the Zigbee Application Framework architecture and how the two code bases are separated.

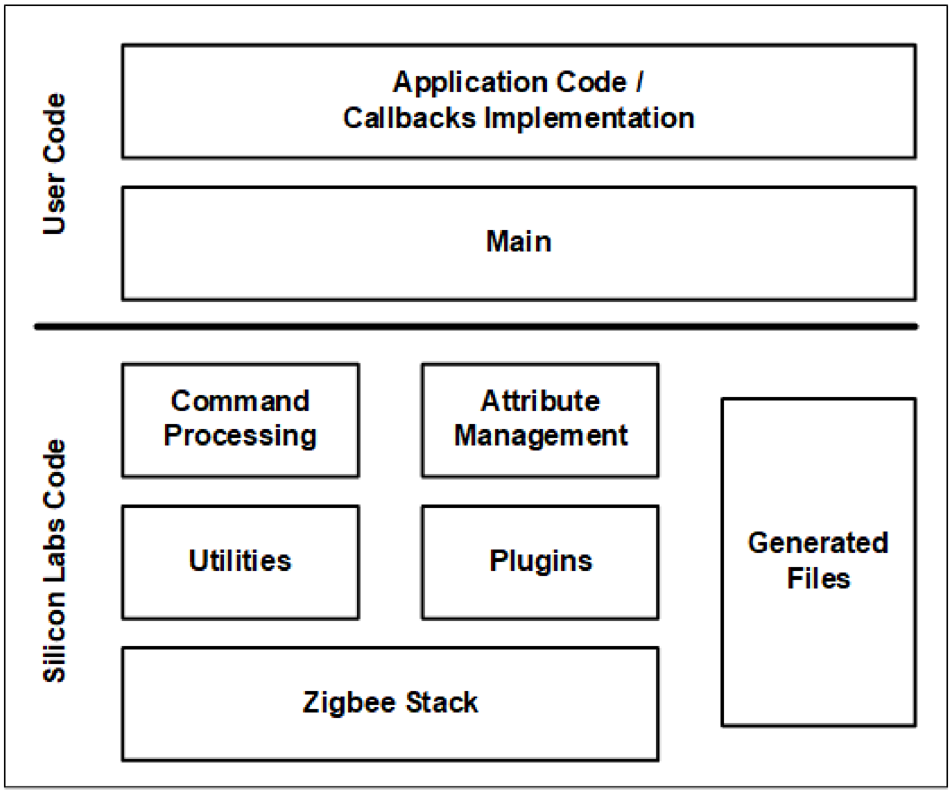


Figure 2.1. Zigbee Application Framework Architecture

Each application has its own *main.c* which implements the `main()` function and the main loop.

The Silicon Labs GSDK is based on a component structure, where a component describes a software module (files, defines, and so on) with a well-defined function. The Zigbee Application Framework Common component included in `app/framework/common` consumes the Zigbee Stack handler interface and integrates the Zigbee Application Framework into the Zigbee EmberZNet PRO stack. This component provides a compile-time subscription mechanism for other Zigbee components. When a component subscribes to one of the stack handlers, a function call to the component callback is generated and will be invoked every time the stack handler is invoked. In addition, two main files are located in the *app/framework/util* directory, one (*af-soc.c*) for a System-on-Chip (SoC) and the other (*af-host.c*) for a host micro-processor paired with a Network Co-Processor (NCP).

For example, the sample application projects subscribe to the `emberIncomingMessageHandler()` stack handler and pass all incoming messages off to the Zigbee Application Framework for command processing. Once incoming messages are processed, they are passed off to the appropriate cluster for handling.

The application can choose to implement any of the public Application Framework level stack callbacks by simply declaring such callbacks in the application code. Every sample application included in the Silicon Labs Gecko SDK Suite (GSDK) implements a subset of callbacks in the application-specific app.c file. Application Framework-level stack callbacks are documented in the Zigbee Application Framework API reference.

3 Project Files

This section lists various files that are created in and used by a Zigbee application project.

3.1 Project Configuration File

<project_name>.slcp

This is the top-level project configuration file.

3.2 Application Source Files

Any number of C files in the project's top directory can be created. The only requirement is that an implementation of `main()` must be present in one of these files.

3.3 Makefiles

Makefiles are generated into the project directory by the Project Configurator when using the GCC compiler. Wth IAR, an .ewp project file is generated instead of makefiles.

3.4 ZCL-Generated Files

Generated files reside in the project's *autogen* directory. You should never modify them manually because manual changes are erased with every re-generation. 'zap' stands for ZCL Advanced Platform. This partial list discusses the generated files that you might need to refer to for various definitions and declarations:

- *zap-command.h*: Generated macros for producing client-side command payloads prior to sending them out over the air; also contains prototypes for the server-side command handlers.
- *zap-config.h*: A generated file that configures the Zigbee Application Framework's static data structures. This allows attribute metadata to be shared across endpoints and each endpoint to have its own space for attribute storage. The *#defines* in the *zap-config.h* file are used by the *app/framework/util/attribute-storage.c* file to configure all the application's attribute-related data. It also contains information about command discovery, based on the selection of incoming and outgoing for commands in the Zigbee Cluster Configurator. See *AN1325: Zigbee Cluster Configurator User's Guide* for more information.
- *zap-id.h*: This file contains all the static IDs for various ZCL entities such as cluster IDs, attribute IDs, and others.
- *zap-tokens.h*: If you are including any attributes in tokens (persistent memory) for a platform that supports tokens, this file is generated by Project Configurator to configure your token storage.
- *zap-type.h*: This file contains all the type definitions for the ZCL—enums, structs, and other entities that are created from XML files.

4 Zigbee Application Framework API and Directory Structure

The Zigbee Application Framework's API declarations are provided in *app/framework/include/af.h*. The *Application Framework API Reference* is provided with your installation as well as online at https://docs.silabs.com/zigbee/latest/zigbee-af-api/appframework.

APIs for getting information about endpoints and attributes are included in *app/framework/util/attribute-storage.h*. For instance, to determine if an endpoint contains a certain attribute, use the function `emberAfContainsAttribute()`. It returns a Boolean indicating if the requested attribute and cluster are implemented on the specific endpoint.

Directories named in this section are found in the Simplicity Studio Zigbee protocol SDK folder (<GSDK location>*protocol**zigbee*) as follows:

- *app/framework*: All the Zigbee Application Framework code is in app/framework. Major portions of the code have been broken out into their own directories.
- *app/framework/common*: Zigbee Application Framework common code that provide basic infrastructure for every Zigbee application, such as seamless integration with OS, integration with the Power Manager, application-level event system APIs, implementation of stack handlers and corresponding application and component dispatching.
- *app/framework/cli*: Code related to the Zigbee Application Framework's implementation of the CLI.
- *app/framework/include*: All of the external APIs for the Zigbee Application Framework. This directory mirrors the use of the include directory in the stack. It is intended to be the single location for all externally-facing application interfaces.
- *app/framework/plugin*, *app/framework/plugin-host*, *app/framework/plugin-soc*: All application framework component code resides here, including all the Silicon Labs ZCL cluster implementations.
- *app/framework/scenarios*: Includes all sample application scenarios that use the Zigbee Application Framework. You can open these sample scenarios within Project Configurator by starting a new project.
- *app/framework/security*: All utility code related to Zigbee security.
- *app/framework/util*: Includes message processing and any other utility code used by the Zigbee Application Framework. This directory contains the most important features of the Zigbee Application Framework. Attribute storage files that manage attributes for multiple endpoint support are included in this directory. In addition, the API used for accessing, reading, and writing attributes is included in the *attribute-table.h*, and *attribute-storage.h* files.
- *<GSDK location>\app\zcl* Includes configuration and template files used by Project Configurator. When you point Project Configurator at a stack installation, it looks into this directory to load XML descriptions of the most current ZCL implementation as of the release of that stack. You may load your custom cluster .xml files into your project by clicking **Add Custom ZCL** in Zigbee Cluster Configurator.

5 ZCL Concepts and Definitions

5.1 Clusters

Each Zigbee cluster defines an application-level protocol. A set of these protocols (or clusters) defines the functionality of a particular Zigbee device. Anyone with a networking background can think of a cluster as an application protocol that has been encapsulated within the Zigbee specification.

The Zigbee Cluster Library (ZCL) is a document that specifies the clusters used by Zigbee devices. The original ZCL document had 30 clusters, most of which were specified as required or optional by at least one device in the Zigbee application profile. The Smart Energy (SE) application profile uses some of the clusters specified in the ZCL but also specifies new clusters that are unique to SE.

5.2 Devices

A Zigbee device can be thought of as a collection of clusters. For example, an on/off light switch and an on/off light are two devices in the Zigbee 3.0 specification. All the devices within a profile must use the same type of security. There are recommendations on polling rates, start-up parameters, what kind of ZDO messages should be implemented, and so on, with the idea being that these devices must interoperate on the same network. If devices have different security settings, they cannot join together. If a user buys a Zigbee 3.0 device from company A and buys another Zigbee 3.0 device from company B, because they use the same application profile, the devices should be able to join work together.

If two Zigbee devices are on a certified Zigbee stack, they can route for each other. In other words, they can exchange messages at the application level. Interoperability at the application level is not guaranteed until devices use an application profile. These standard application profiles enable Project Configurator to generate Zigbee- compliant applications.

The Zigbee 3.0 on/off light has the following implementations:

- Identify server (required by all)
- Groups server
- Scenes server
- On/Off server

The Zigbee 3.0 on/off light switch has the following implementations:

- Identify client
- Groups client
- Scenes client
- On/Off client

The on/off light switch can send an on/off or toggle message that the on/off light is required to understand and accept.

5.3 Profile ID

When configuring an endpoint, you must specify a Profile ID. If you are developing a Zigbee 3.0 application, you must specify the profile ID 0x0104. When developing an SE application, you must specify the profile ID 0x0109.

5.4 More About Clusters and Attributes

Clusters specify two things: attributes and commands. Attributes are well-defined pieces of data that are stored on a device and can be read (and sometimes written) by external devices. Commands specify Over-The-Air (OTA) messages that are exchanged. Each command defined by the ZCL is unidirectional in the sense that it is sent by one side (either the client or server) and received by the other. A device can implement only one side of a cluster, or it can implement both sides of a cluster.

For instance, a Zigbee On/Off Light implements the server side of the “on/off” cluster, while the Zigbee On/Off Light Switch implements the client side of the “on/off” cluster. This defines that the Light Switch sends “on”, “off”, and “toggle” commands that the Light can receive (and understand). It also defines that the Light stores a Boolean attribute called “on/off” representing the current state of the device.

Note: Zigbee often uses the terms “in-cluster-list” and “out-cluster-list” instead of server and client. An “in-cluster-list” is the list of supported server clusters, and the “out-cluster-list” is the list of supported client clusters.

In most cases, the server side of a cluster contains all the attributes, and the client side is the side that initiates an OTA exchange. For the most part, the client sends a message and the server answers that message.

5.4.1 Example: The Identify Cluster

The client/server interaction defined by the ZCL is illustrated in the Identify example shown in the following figure.

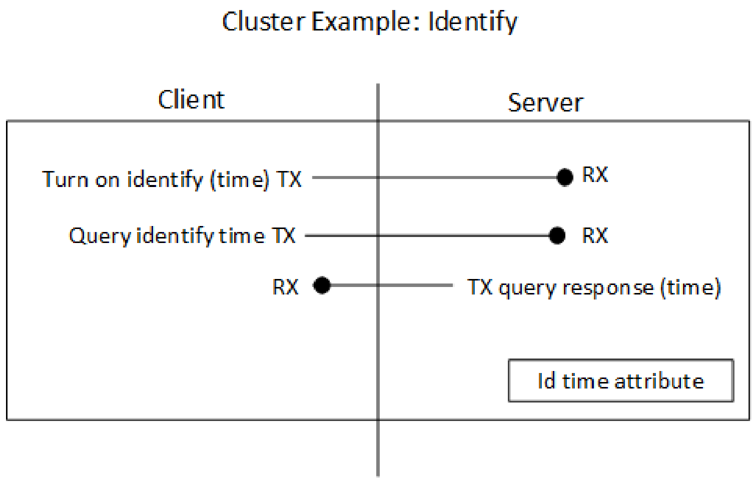


Figure 6.1. Identify Cluster Example

Like many clusters, the Identify cluster is a simple cluster. The lower right corner shows the single attribute—identify time.

5.4.1.1 Identify Cluster Use Case

A user is provisioning a network of 12 lights in one room and must connect six of those lights to a single switch. The MAC address of each light is used to associate it with the switch. The MAC addresses for all 12 lights can be discovered by using a provisioning tool and a low power broadcast or by using a token (set when they were installed) on each light indicating room or location. The “Identify” functionality can be used to figure out which six MAC addresses correspond to the six physical lights that the user wants bound to a switch. Using the Identify cluster, the user can tell each light individually to “identify” itself (for example, blink so that it can be seen).

The Identify cluster defines the protocol for how devices are put into and taken out of identify mode. In the above example, the provisioning tool implements the client side of the identify cluster and the light or the device that needs to be identified implements the server side.

When the client wants to tell a device to “start identifying,” it sends the “Identify” command and specifies a period of time in seconds for which to continue identifying. The device stops identifying when the identify time attributes (decremented each second) reaches 0 or if the device receives an “Identify” command with identify time value of 0.

The first message in the above figure turns on “identify.” When identify is turned on, a time period is also included in the message. For example, suppose identify is turned on for 30 seconds. The second message shows the client (provisioning device) querying the server (light) to find out how much time is left in the identify process.

Because a query message can be sent to a group, it is possible to put a device into a mode where it is identifying, and then use a PC or provisioning tool and figure out which device in the group is identifying. This is useful if a device supports a physical cue to start identifying. Then a device can be poked (button press, magnet wand, and so on) to start identifying, and a group message can be sent to map the MAC address to the physical device.

5.4.2 Example: The Temperature Measurement Cluster

The following figure illustrates another example of a temperature measurement cluster.

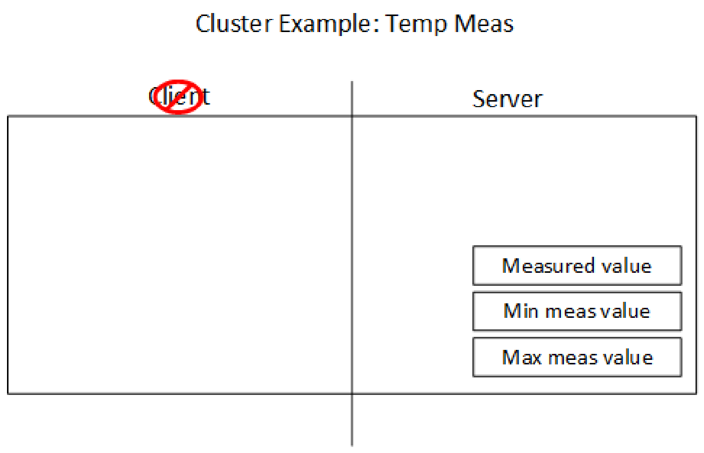


Figure 6.2. Temperature Measurement Cluster Example

Notice that this cluster has no commands, it only has attributes. In this case, the device implements measurements of temperature, such as a thermostat. This example includes a measured value, a minimum measured value, and a maximum measured value. With no commands, this cluster relies on the global commands defined in the ZCL. The global commands define messages for reading, writing, discovering, and reporting attributes.

Note: Fourteen global commands such as read attributes, write attributes, configure attribute reporting, discover attributes, and report attribute values are included in this cluster. Clusters that only include attributes are simple to understand and implement because the global commands are already implemented.

To read the value of an attribute of this cluster, a global read attributes command is used. This message contains the attribute ID of the attribute to read. In combination, the cluster and the attribute ID provide unique identification. On the embedded side, this makes it possible to centralize all the attributes in a single table. All the code for those attributes is generic, shared code.

As a result, for example, when adding four of the temperature-measuring-sensing clusters, the impact on flash is minimal because there are no additional commands. The impact on RAM depends on the number of attributes added per cluster.

The application-level protocol provided by the ZCL makes it possible for two companies to develop products separately and have them work together without having to test them together.

6 Zigbee Application Framework Callback Interface

The Zigbee Application Framework callbacks are intended to be used as a means to remove all customer code from the Zigbee Application Framework. Generally, when a callback is called, the Zigbee Application Framework gives the application code a first opportunity at an incoming message or requesting some piece of application data. Within the callback API, some callbacks return a Boolean value indicating that the message has been handled and no further processing will be done. If your application is doing something that conflicts with the Zigbee Application Framework's handling of a particular message, return TRUE to indicate that the message was handled. This ensures that the Zigbee Application Framework does not interfere with your application's handling of the message.

6.1 Implementing Callbacks

A callback is a C function that gets invoked by the Application Framework when certain conditions are met. A basic **weak** implementation of all callbacks is provided by the Application Framework. The application can override each of these weak definitions by simply adding a callback implementation to some application-level source file. For example, you may create *my_callbacks.c* file by clicking **New** in Simplicity Studio's Project Explorer focused on a given project, add a callback implementation to this file, and save it. The file automatically becomes a compilation unit in the project and the callback implementation will be compiled and linked during subsequent builds.

6.2 Callback Types

The Zigbee Application Framework utilizes the following callback types:

- Global Callbacks
- ZCL command handling callbacks
- Component-Specific Callbacks
- Stack Callbacks

The following figure illustrates an example of Zigbee Application Framework callback types.

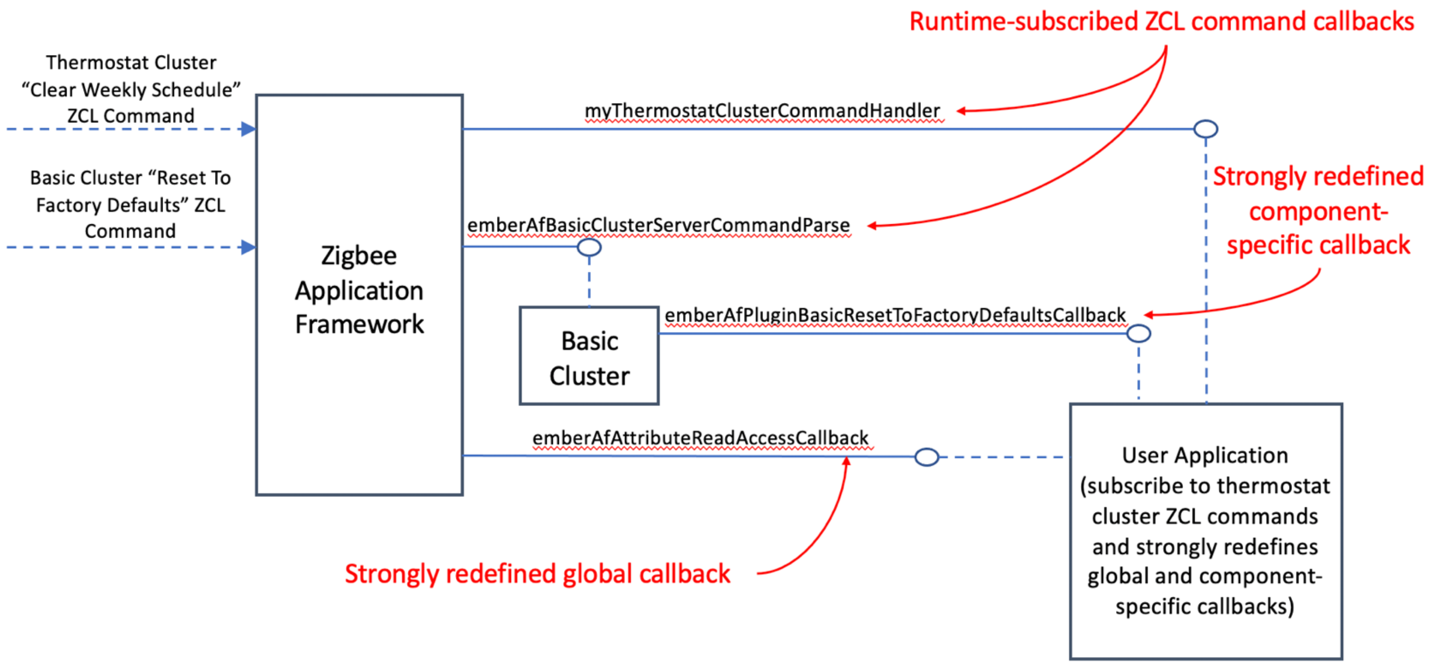

Runtime-subscribed ZCL command callbacks
Thermostat Cluster "Clear Weekly Schedule" ZCL Command
Basic Cluster "Reset To Factory Defaults" ZCL Command
Zigbee Application Framework
myThermostatClusterCommandHandler
emberAfBasicClusterServerCommandParse
Strongly redefined component-specific callback
Basic Cluster
emberAfPluginBasicResetToFactoryDefaultsCallback
emberAfAttributeReadAccessCallback
Strongly redefined global callback
User Application (subscribe to thermostat cluster ZCL commands and strongly redefines global and component-specific callbacks)

Figure 5.1. Zigbee Application Framework Callback Types

The above figure illustrates a project where:

- ZCL Basic Cluster implementation is provided by the GSDK, which uses runtime subscription mechanism to subscribe the `emberAfBasicClusterServerCommandParse` function to the Basic Cluster ZCL commands (server side).

- ZCL Thermostat Cluster is not implemented in the GSDK but is implemented in the application. The application uses a runtime subscription mechanism to subscribe myThermostatClusterCommandHandler to the Thermostat Cluster ZCL commands as described in section 5.4.
- Application implements a component-specific callback *emberAfPluginBasicResetToFactoryDefaultsCallback* by strongly redefining it.
- Application implements a global callback *emberAfAttributeReadAccessCallback* by strongly redefining it.

6.3 Global Callbacks

All global commands fall into this category. The Zigbee Application Framework contains handling code for global ZCL commands. If any global command callback returns TRUE, this indicates that the command has been handled by the application and no further command handling should take place. If the callback returns FALSE, then the Zigbee Application Framework continues to process the command normally.

You can find a full list of Global callbacks at https://docs.silabs.com/zigbee/latest/zigbee-af-api/global-callback.

6.3.1 Global Callback Example

The pre-command received callback （*emberAfPreCommandReceivedCallback(EmberAfClusterCommand* cmd*） is called after a ZCL command has been received but has not yet been processed by the Zigbee Application Framework's command handling code. The command is parsed into a useful struct *EmberAfClusterCommand* that provides an easy way to access relevant data about the command including its *EmberApsFrame*, message type, source, buffer, length, and any relevant flags for the command. This callback also returns a Boolean value indicating if the command has been handled. If the callback returns TRUE, then it is assumed that the command has been handled by the application and no further action is taken.

6.4 ZCL Command Handling Callbacks

The Zigbee Application Framework provides a runtime mechanism that enables the application to subscribe to ZCL commands related to a certain ZCL cluster. Specifically:

```
sl_status_t sl_zigbee_subscribe_to_zcl_commands(uint16_t cluster_id,
                                                 uint16_t manufacturer_id,
                                                 uint8_t direction,
                                                 sl_service_function_t service_function)
```

This API enables the application to subscribe to incoming ZCL commands related to a specific cluster ID, a specific manufacturer ID (if not present, simply pass `0xFFFF`), a direction (either `ZCL_DIRECTION_CLIENT_TO_SERVER` or `ZCL_DIRECTION_SERVER_TO_CLIENT`) and the actual callback to be invoked whenever a matching ZCL command is received. Such a callback must return a value of `EMBER_ZCL_STATUS_SUCCESS` if the command was handled, and a value of `EMBER_ZCL_STATUS_UNSUP_COMMAND` if the callback did not handle the passed command.

Below is an example of a runtime-subscribed ZCL command callback that handles the "stop" command for the "level control" cluster:

```
uint32_t my_command_handler(sl_service_opcode_t opcode,
                            sl_service_function_context_t *context)
{
  assert(opcode == SL_SERVICE_FUNCTION_TYPE_ZCL_COMMAND);

  EmberAfClusterCommand *cmd = (EmberAfClusterCommand *)context->data;

  switch (cmd->commandId) {
    case ZCL_STOP_COMMAND_ID:
    {
      // ZCL command structs and parsing functions are implemented in the
      // generated zap-cluster-command-parser.[c,h] files.
      sl_zcl_level_control_cluster_stop_command_t cmd_data;

      if (zcl_decode_level_control_cluster_stop_command(cmd, &cmd_data)
          != EMBER_ZCL_STATUS_SUCCESS) {
        return EMBER_ZCL_STATUS_UNSUP_COMMAND;
      }

      // Handle the command here

      // Send a default response back to the client
      emberAfSendDefaultResponse(EMBER_ZCL_STATUS_SUCCESS);

      // handle the command here

      return EMBER_ZCL_STATUS_SUCCESS;
    }
  }

  return EMBER_ZCL_STATUS_UNSUP_COMMAND;
}
```

The application must subscribe to the Level Control cluster commands (server side), by invoking the following – typically at initialization time:

```
void app_init(void)
{
  sl_zigbee_subscribe_to_zcl_commands(ZCL_LEVEL_CONTROL_CLUSTER_ID,
                                      0xFFFF,
                                      ZCL_DIRECTION_SERVER_TO_CLIENT,
                                      my_command_handler);
}
```

Notice that in the previous example, the application chose to implement a single command and used the ZCL command parsing functions that are generated in the `zap-cluster-command-parser.[c,h]`. When such a command is received (and handled), the callback returns `EMBER_ZCL_STATUS_SUCCESS` while, when other commands belonging to the same cluster are received, the callback returns `EMBER_ZCL_STATUS_UNSUP_COMMAND`.

Finally, multiple software modules can subscribe to the same cluster, though every command belonging to a ZCL cluster should be handled by a single software module. If a cluster is not enabled in the ZCL Configurator tool, the application framework responds with a default response with status `EMBER_ZCL_STATUS_UNSUPPORTED_CLUSTER`. If the cluster is enabled in the ZCL Configurator tool, but no software module is handling the command, the application framework responds with status `EMBER_ZCL_STATUS_UN-SUP_COMMAND`.

6.5 Component-Specific Callbacks

Callbacks of this type are calls into the application code from the internal component logic. The full list of component-specific callbacks can be found at https://docs.silabs.com/zigbee/latest/zigbee-af-api/af-callback. Additionally, a link to the list of callbacks offered by each component appears in the component's tile in the Project Configurator. You can implement these callbacks as described in 5.1 Implementing Callbacks.

For example, the Basic Server Cluster software component exposes the *emberAfPluginBasicResetToFactoryDefaultsCallback* callback (as displayed in the Zigbee Cluster Library **Common** component), which you may choose to implement by simply adding an implementation of this function to one of the C files in the project.

6.6 Stack Callbacks

The Application Framework also provides stack-level callbacks that enable the application to react to stack-specific events. Typically, these stack callbacks match the stack handlers provided by the Zigbee stack libraries that are consumed by the Application Framework. For example:

- void emberAfStackStatusCallback(EmberStatus status)
- void emberAfEnergyScanResultCallback(uint8_t channel,int8_t maxRssiValue)
- void emberAfNetworkFoundCallback(EmberZigbeeNetwork *networkFound, uint8_t lqi, int8_t rssi)
- and so on.

A full list of these stack callbacks can be found at https://docs.silabs.com/zigbee/latest/zigbee-af-api/stack-callback.

6.7 Callback Flow for Message Processing

The following figure shows how a message received by the Zigbee Application Framework's implementation of `emberIncoming-MessageHandler` is processed and flows through the framework code and out to the application implemented callbacks.

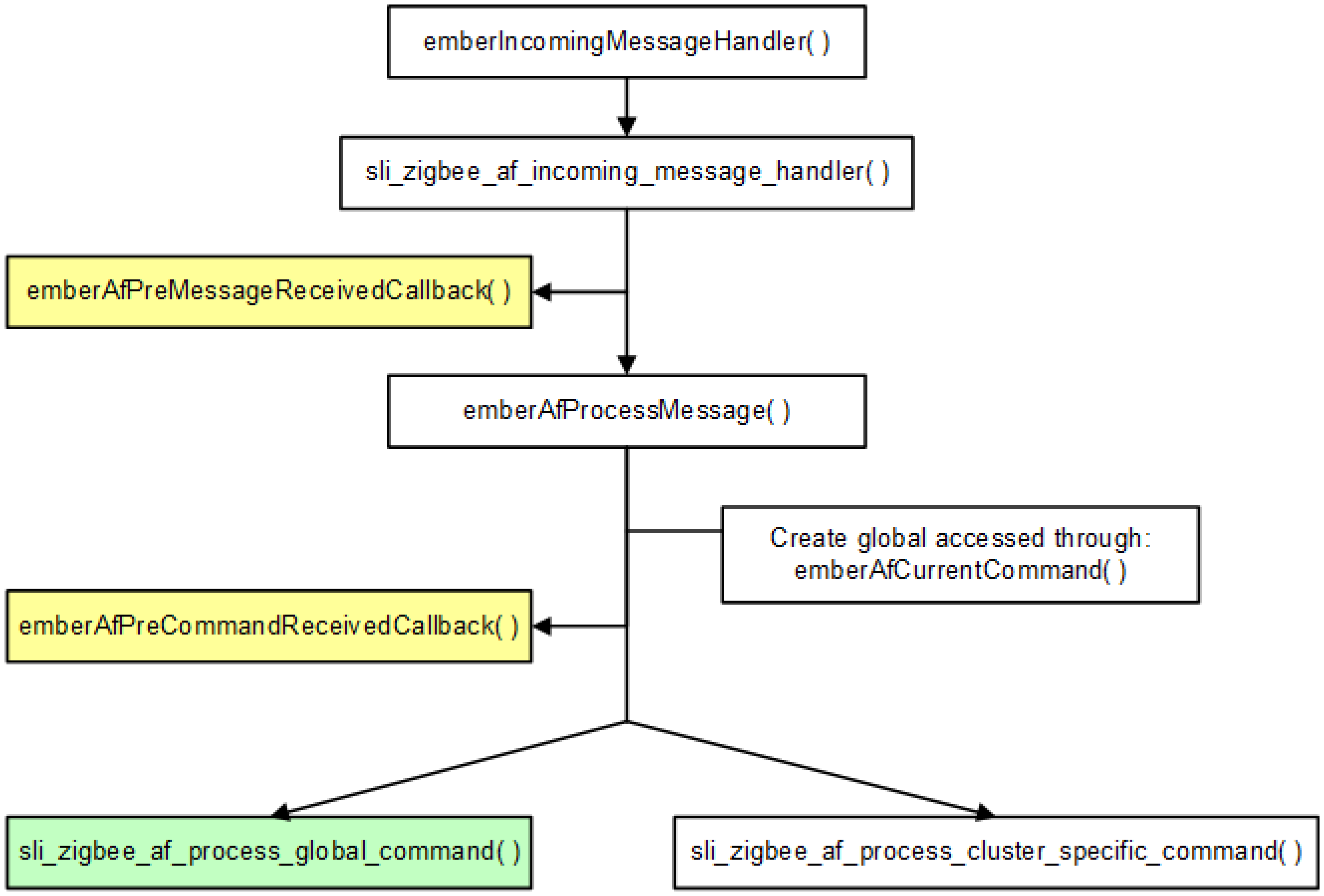

emberIncomingMessageHandler( )
sli_zigbee_af_incoming_message_handler( )
emberAfPreMessageReceivedCallback( )
emberAfProcessMessage( )
Create global accessed through: emberAfCurrentCommand( )
emberAfPreCommandReceivedCallback( )
sli_zigbee_af_process_global_command( )
sli_zigbee_af_process_cluster_specific_command( )

Figure 5.2. Incoming Message Flow

Once the incoming message is determined to be an incoming global command, it is passed off to the global command handling for processing, as shown in the following figure.

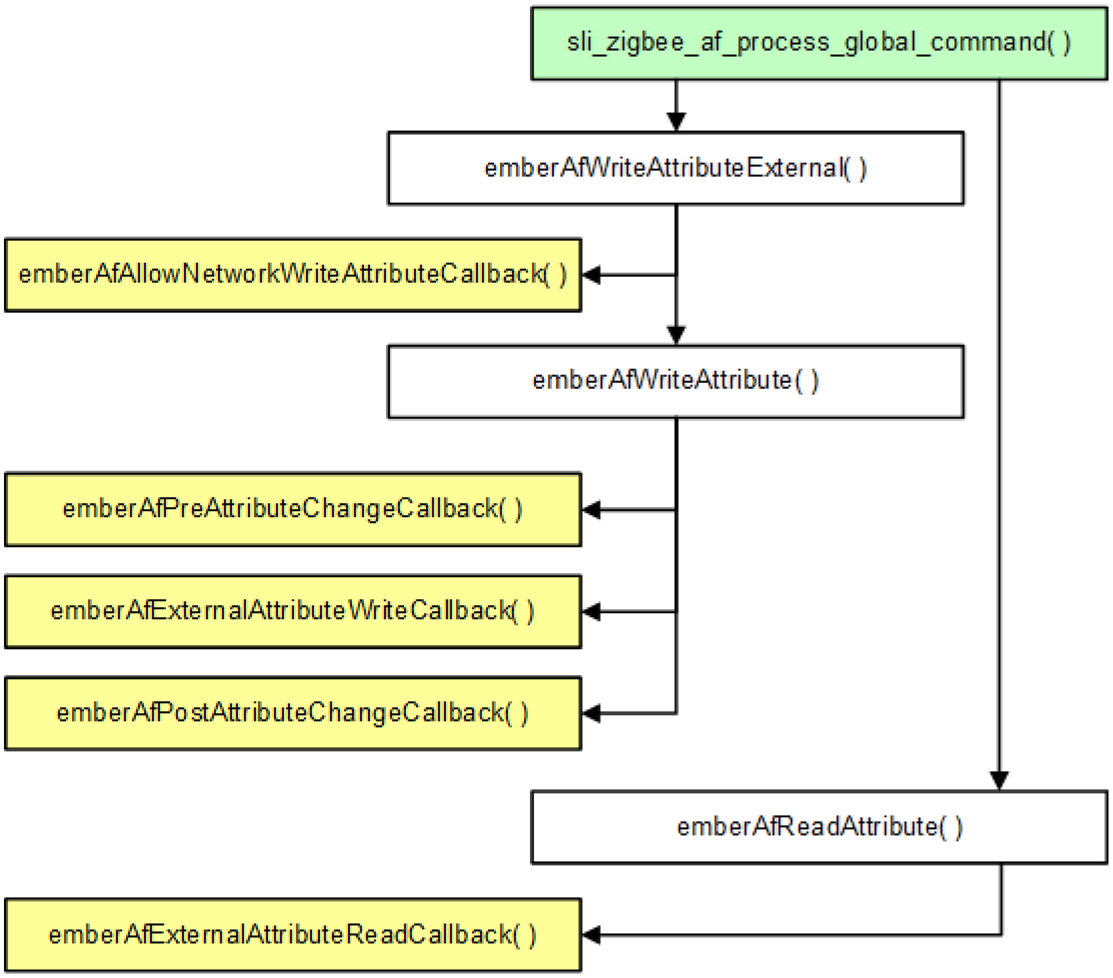

sli_zigbee_af_process_global_command( )
emberAfWriteAttributeExternal( )
emberAfAllowNetworkWriteAttributeCallback( )
emberAfWriteAttribute( )
emberAfPreAttributeChangeCallback( )
emberAfExternalAttributeWriteCallback( )
emberAfPostAttributeChangeCallback( )
emberAfReadAttribute( )
emberAfExternalAttributeReadCallback( )

Figure 5.3. Global Command Handling

Otherwise, if it is found to be a cluster-specific command, it is passed off to the cluster-specific command processing.

6.8 Command Callbacks Implementation Notes

6.8.1 Command Callback Context

All command-related callbacks are called from within the context of the `emberIncomingMessageHandler`. This means that Zigbee APIs that are available to the application within that context are available within the command handling callbacks as well. These APIs are listed in the stack API file located at *stack/include/message.h*. The stack APIs that are available in the command callbacks are listed in the stack message header located at *stack/include/message.h* and include:

```
emberGetLastHopLqi()
emberGetLastHopRssi()
emberGetSender()
emberGetSenderEui64()
emberGetBindingIndex()
emberSetReplyBinding()
emberNoteSendersBinding()
```

6.8.2 Array Handling in Command Callbacks

Any Zigbee message that contains an array of arguments is passed as an int8u* pointer to the beginning of the array. This is done even when the Zigbee Application Framework knows that the arguments in the array may be of another type, such as an uint16_t or uint32_t, because of byte alignment issues on the various processors on which the Zigbee Application Framework may run. Developers implementing the callback must parse the array and cast its elements appropriately for their hardware.

7 Time Handling

The Zigbee Application Framework provides a single API for accessing the current time on the system—`int32u emberAfGetCurrentTime()`—which is described in *app/framework/util/time-util.h*. This section describes how the function is implemented in *app/framework/util/time-util.c*.

If the ZCL time cluster server is implemented on the system, then this function retrieves the time from the server through the function call `int32u emberAfTimeClusterServerGetCurrentTime()`. In this case, the time is read from the time cluster server's time attribute and returned. If the time cluster server is not implemented, then `emberAfGetCurrentTime` calls *emberAfGetCurrentTimeCallback*.

If your device needs to know the current time but does not implement the time cluster server component, it is responsible for maintaining its own time somewhere on the system and returning that time through the *emberAfGetCurrentTimeCallback* when it is requested. This is especially important for SE devices that do not implement the time cluster server like an In-Premise Display (IPD). Essentially the IPD is on its own when it comes to time management. It would be outside the ZCL specification (as currently interpreted) for a non-Energy Service Portal to implement the time cluster server. Therefore, the IPD must maintain its own knowledge of time and provide it to the Zigbee Application Framework when requested through the *emberAfGetCurrentTimeCallback*.

If your application includes the time cluster server, the time cluster server code always tries to initialize and update the time server's time attribute through the *emberAfGetCurrentTimeCallback*. If the *emberAfGetCurrentTimeCallback* returns 0, then the time cluster server increments the stored attribute once per second. Thus, you can use the time cluster server to store and maintain real time on the system without implementing the *emberAfGetCurrentTimeCallback*, if the actual time value can be synced from another device on the system and written into the time server's time attribute. For more information on how time is handled by the bundled implementation of the time cluster server, see *app/framework/plugin/time-server/time-server.c*.

8 Events

The Zigbee Application Framework and its associated cluster code use the Zigbee Stack event mechanism to schedule events on both the SoC and the host. Use of the Zigbee event mechanism saves code and RAM and works better with sleepy devices.

At a high level, the event mechanism provides a central location where all periodic actions taken by the device can be activated and deactivated based on either some user input, an OTA command, or device initialization. The event mechanism is superior to the constant tick mechanism it replaces because it allows the Zigbee Application Framework to know precisely when the next action is going to occur on the device. This is extremely important for sleepy devices that need to know exactly when they must wake up to take some action or more importantly that they cannot go to sleep because some event is in progress. The application can create and use its own events.

8.1 Creating Application Events

The Zigbee Application Framework uses the Zigbee standard event mechanism to control and run application events within the Zigbee Application Framework. The stack's event mechanism is documented in the *zigbee_app_framework_event.h* header file located at *app/framework/common*.

An application can create a new event by simply declaring a new variable of *sl_zigbee_event_t* type. Such variable should be initialized before being used by invoking the `sl_zigbee_event_init()` API. Once the event is initialized, the following APIs can be invoked:

- `void sl_zigbee_event_set_active(sl_zigbee_event_t *event)`
- `void sl_zigbee_event_set_inactive(sl_zigbee_event_t *event)`
- `bool sl_zigbee_event_is_scheduled(sl_zigbee_event_t *event)`
- `uint32_t sl_zigbee_event_get_remaining_ms(sl_zigbee_event_t *event)`
- `void sl_zigbee_event_set_delay_ms(sl_zigbee_event_t *event, uint32_t delay)`
- `void sl_zigbee_event_set_delay_qs(sl_zigbee_event_t *event, uint32_t delay)`
- `void sl_zigbee_event_set_delay_minutes(sl_zigbee_event_t *event, uint32_t delay)`

8.1.1 Event Struct and Event Handler

An application event consists of two parts:

- The event handler, called when the event fires.
- The *sl_zigbee_event_t* struct which is used to schedule the event. Scheduled events end up in the Zigbee Application Framework event queue which the Zigbee Application Framework uses to keep track of when the next event will occur for the purposes of sleeping.

8.1.2 Application Event Example

The Z3Light sample application uses a custom event to manage its state. The event consists of two parts:

- The *sl_zigbee_event_t* struct called *commissioning_led_event*.
- The event handler which is called each time the event fires. The event handler is called the `commissioning_led_event_handler`. The event handler and event struct are included in the *app.c* file shipped with the sample application.

8.2 How Cluster Events Are Created

Every cluster includes a server and a client "tick" callback. The Zigbee Cluster Configurator generates a declaration of a *sl_zigbee_event_t* struct for each cluster server or client on each endpoint. The actual declarations are generated in the *zap_event.h* header which is included and used in the Zigbee Application Framework's event code in *app/framework/util/af-event.c*.

Initialization of endpoint-specific events must be accomplished using the dedicated API `sl_zigbee_endpoint_event_init()`.

8.3 How Cluster Events Are Scheduled

The component or application code can manage cluster-related events in the event table by using the Zigbee Application Framework's event management API. This API consists of two functions: `sl_zigbee_zcl_schedule_cluster_tick` and `sl_zigbee_zcl_deactivate_cluster_tick`.

A *tick* is the basic unit of time used in the event system. The duration of a tick depends on the platform that is being used. Using the current Zigbee platform, one tick is approximately equal to:

$$\frac{(milliseconds\ per\ seconds)}{MILLISECOND\_TICKS\_PER\_SECOND} = \frac{1000}{1024} = .9765625 \text{ milliseconds per second}$$

where `MILLISECOND_TICKS_PER_SECOND` is the number of clock ticks per second. Therefore, when `sl_zigbee_zcl_schedule_cluster_tick` is called with a value of `t` for the `delayMs` argument, the event will be run in no less than

$$\left\lceil t * \left(\frac{(milliseconds\ per\ seconds)}{MILLISECOND\_TICKS\_PER\_SECOND}\right)\right\rceil = \lceil t * .9765625 \rceil \text{ milliseconds.}$$

Of course, the empirical error in this value depends on the reliability of the clock source.

8.3.1 sl_zigbee_zcl_schedule_cluster_tick

`sl_zigbee_zcl_schedule_cluster_tick` uses the endpoint, cluster id, and client/server identity to find the associated event in *the sl_zigbee_event_context_t* event context table. This table is generated by the Zigbee Cluster Configurator into *zap-event.h*. If it cannot find the event table entry, `sl_zigbee_zcl_schedule_cluster_tick` returns the EmberStatus *EMBER_BAD_ARGUMENT* to the caller. If it finds the event table entry, then it schedules the event to take place in the number of milliseconds requested by the caller and it returns *EMBER_SUCCESS*.

```
EmberStatus sl_zigbee_zcl_schedule_cluster_tick (int8u endpoint,
                                                  int16u clusterId,
                                                  boolean isClient,
                                                  int32u timeMs,
                                                  EmberAfEventSleepControl sleepControl);
```

The *EmberAfEventSleepControl* argument allows the caller to indicate what the device may do while the event is active in the event table. This value is only relevant for sleepy devices; it has no effect for devices that do not go to sleep. The possible values for *EmberAfEventSleepControl* are enumerated in *app/framework/include/af-types.h*, as follows:

- EMBER_AF_OK_TO_HIBERNATE means that the application may go into prolonged deep sleep until the event needs to be called. Use this sleep control value if the scheduling code does not care what the device does up to the point when the event is called.
- EMBER_AF_OK_TO_NAP means that the device should sleep for the nap period and should wake up to poll between naps until the event is called. Use this sleep control value if the scheduling code wants the device to poll periodically until the event is called. This is particularly useful if the scheduled event is a timeout waiting for some reply from another device on the network. If the event is a timeout, you do not want the device to go into hibernation until the timeout is called because it will never hear the message it is waiting for, thereby guaranteeing that the timeout will be called.
- EMBER_AF_STAY_AWAKE means that the device should not sleep at all but should stay awake until the event is called. Use this event if you are scheduling a very frequent event and do not want the device to nap for a very short period of time because the device will poll each time it wakes up. If the device is held out of sleep entirely, it will poll once per second.

8.3.2 sl_zigbee_zcl_deactivate_cluster_tick

The deactivation function is used to turn off an event. This function should be called when the scheduled event is called to ensure that the event code does not continue to call the event. It may also be called before the event is called if the event is no longer necessary.

Note: In the Zigbee Application Framework `sl_zigbee_zcl_deactivate_cluster_tick` is automatically called before the event fires to ensure that the event will not continue to be called on every tick.

`deactivate_cluster_tick` is like `schedule_cluster_tick` in that it takes most of the same arguments, but it also has to locate the correct event in the event context table before shutting it off.

```
EmberStatus sl_zigbee_zcl_deactivate_cluster_tick (int8u endpoint,
                                                    int16u clusterId,
                                                    boolean isClient);
```

9 Attribute Management

9.1 ZCL Attribute Configuration

In the Zigbee Application Framework , attribute storage is managed by two .c files—*app/framework/util attribute-storage.c* and *attribute-table.c*)—as well as a single header file *zap-config.h* which Project Configurator generates from the application configuration. The end-point configuration header file sets up the attribute metadata and the actual attribute storage.

You have several options for attribute storage:

- External Attributes
- Persistent Memory Storage
- Singleton
- Attribute Bounding
- Attribute Reporting

9.1.1 Attribute Storage Endianness

All attributes that are not a ZCL string type are expected to be stored with the same endianness as the platform on which the application is being run. On the EFR32, this means that attributes with a non-string type are expected to be stored with the least significant byte first (LSB, little endian).

9.1.2 Implications of Attribute Storage Endianness

The Zigbee protocol demands that all values that are not a string or byte array type be sent over the air in a Little Endian or LSB format. The implication of this for the EFR32 and other little-endian platforms is that no byte swapping needs to be done with attributes when they are pulled from attribute storage and sent over the air. Conversely, when the Zigbee Application Framework is run a big-endian processor, like certain UNIX host systems for EZSP-UART, it will perform byte swapping on integer type attributes before they are sent over the air so that they are sent in the LSB format.

The previous section says that attributes are expected to be stored in the proper format because no byte swapping is done on local writes into the attribute table from native types or from byte arrays. Therefore, it is up to the user to ensure that byte arrays which represent Zigbee integer types but do not map directly to a native type like the int16u or int32u are represented in the byte order of the application platform.

If you are writing an application that may be run on several platforms with different endianness, you may check the endianness of the platform by using the #define BIGENDIAN_CPU provided in the platform header platform/common/inc/sl_endianness.h.

Example: Consider the simple-meter-server component’s test code located at app/framework/plugin/simple-metering-server/simple-metering-test.c. This test code pulls the simple metering daily summation attribute from the attribute table, updates it, and puts it back into the attribute table. Unfortunately, the daily summation is a Zigbee 48-bit unsigned integer, which is not a native data type.

The Zigbee platform for the EFR32 family of processors has no native data type like an int48u into which the daily summation attribute can be read and simply manipulated. As a result, the attribute must be read into a byte array and the byte array must be manipulated before it is written back into the attribute table. During this manipulation it is important for the developer to remember that on the EFR32 the attribute is stored LSB, so the manipulation must be done LSB. Otherwise, the value will be stored and sent over the air in the wrong format when it is read by another device on the network.

Note: For EZSP host applications, since all attributes are stored on the host processor in an NCP + Host design, it is the endianness of the host that counts for attribute storage.

9.1.3 External Attributes

You may wish to store the values for some attributes in a location external to the Zigbee application framework. This type of storage makes the most sense for attributes that must be read from the hardware each time they are requested. In a case like this, no real reason exists to store a copy of the attribute in some wasted RAM space within the Zigbee application framework.

Mark an attribute as externally located by editing the cluster in Zigbee Cluster Configurator, editing the attribute, and selecting **External** in the attribute's Storage Option menu. The attribute's metadata will be tagged to indicate that the Zigbee Application Framework should not reserve memory for the storage of that attribute. Instead, when that attribute is to be read or written, the Zigbee Application Framework accesses it by calling `emberAfExternalAttributeReadCallback` and `emberAfExternalAttributeWriteCallback`.

The application is expected to respond to the request immediately. No state machine is currently associated with accessing external attributes that would be able to, for example, start a read and then callback again in a minute to see how the data read is going.

Any attribute that cannot be returned or updated in a timely manner is not currently a candidate for externalization. For attributes of this type, Silicon Labs suggests that you include Zigbee Application Framework storage and update the value in the Zigbee Application Framework on a specific interval within the emberAfMainTickCallback.

9.1.4 Persistent Memory Storage

Silicon Labs System-on-Chip (SoC) chips can store attributes in persistent memory (SIMEEPROM or NVM3). Mark an attribute for persistent memory storage by editing the cluster in Zigbee Cluster Configurator, editing the attribute, and selecting **NVM** in the attribute's **Storage Option** menu. This automatically adds the necessary header file code to the generated *zap-tokens.h* file and marks the attribute as persisted in flash within the attribute's metadata.

Because each host chip has its own way of storing persistent data, the Zigbee Application Framework and Project Configurator do not have a way of persisting attributes on the host. However, you can mark any attribute you wish to persist as 'External' and then handle the data persistence yourself within `emberAfExternalAttributeReadCallback` and `emberAfExternalAttributeWriteCallback`.

9.1.5 Singleton

While ZCL clusters and attributes can be spread across multiple endpoints, it does not make sense to have multiple instances of many of these attributes. For instance, the Basic Cluster may be implemented on three different endpoints, but it does not make sense to store three versions of the mandatory 'ZCL Version' attribute, since each endpoint will likely have the same version. Mark an attribute as a singleton by editing the cluster in Zigbee Cluster Configurator, editing the attribute, and selecting the Singleton checkbox. As a convenience, the Zigbee Application Framework provides a default 'Singleton' modifier for many of the obvious cases. This default modifier can be overridden if you choose.

Attributes marked as singleton are stored in a special singleton storage area in memory. A read or write to any endpoint for one of these attributes resolves to an access of the same location in memory.

9.1.6 Attribute Bounding

Attributes which contain min and max values defined by the Zigbee ZCL specification can be bounded within the Zigbee Application Framework. Mark an attribute as bounded by editing the cluster in Zigbee Cluster Configurator, editing the attribute, selecting the **Bounded** checkbox. When an attribute is bounded, the min and max values defined by the ZCL specification are included in the generated zap-config.h file. When the application attempts to write one of these attributes, the attribute write succeeds only if its value falls within the bounds defined by the ZCL specification.

9.2 Interacting with ZCL Attributes

The Zigbee Application Framework attributes table exposes several APIs that help you do things like read, write, and verify that certain attributes are included on a given endpoint. The prototypes for functions used to interact with the attribute tables are conveniently located in *app/framework/include/af.h*. The API includes:

`emberAfLocateAttributeMetadata:` Retrieves the metadata for a given attribute

Use this function to determine if the attribute exists or is implemented on a given endpoint. You can use the *emberAfAttributeMetadata* pointer returned to access more information about the attribute in question including its type, size, defaultValue and any internal settings for the attribute contained in its mask.

```
EmberAfAttributeMetadata *emberAfLocateAttributeMetadata(int8u endpoint, EmberAfClusterId cluster,
EmberAfAttributeId attribute);
```

The Zigbee Application Framework stores metadata for all the attributes that it contains in CONST memory. It does this for all attributes, including those that may have values stored externally or singletons.

9.2.1 ZCL String Attributes

The String data type is a special case in the ZCL. All strings are MSB with the first byte being the length byte for the string. There is no null terminator or similar concept in the ZCL. Therefore a 5-byte string is 6 bytes long, with the first byte indicating the length of the proceeding string. For example, “05 68 65 6C 6C 6F” is a ZCL string that says “hello.”

10 Command Handling and Generation

10.1 Sending Commands and Command Responses

The Zigbee Application Framework API includes many useful macros for sending and responding to ZCL commands. All of the macros are defined in the file *zap-command.h*. This file is generated for each project. For example, after building project Z3Light the file can be found in *<user workspace>/Z3Light/zap-command.h*.

To send a command, do the following.

Sending a command:

1. Construct a command using a fill macro from the zap-command.h file:

   For example:

   ```
   emberAfFillCommandIdentifyClusterIdentify(identifyTime);
   ```

   `identifyTime` is an int16u defined in the spec as the number of seconds the device should continue to identify itself. This macro fills the command buffer with the appropriate values.
2. Retrieve a pointer to the command EmberApsFrame and populate it with the appropriate source and destination endpoints for your command. Other values in the ApsFrame such as sequence number are handled by the framework, so you do not need to worry about them.
3. Once the command has been constructed, the command can be sent as a unicast, multicast, or broadcast using one of the following functions:

   ```
   EmberStatus emberAfSendCommandMulticast(int16u multicastId);
   EmberStatus emberAfSendCommandUnicast(EmberOutgoingMessageType type, int16u indexOrDes-
   tination);
   EmberStatus emberAfSendCommandBroadcast(int16u destination);
   ```

Sending a response to an incoming command:

Use a similar mechanism to send a response to an incoming command.

1. Fill the response command buffer using the command response macros included in autogen/zap-command.h such as:

   ```
   emberAfFillCommandIdentifyClusterIdentifyQueryResponse(timeout)
   ```

   Timeout is an int16u representing the number of seconds the device will continue to identify itself.
2. You do not need to worry about the endpoints set in the response EmberApsFrame since these are handled by the framework.
3. Send the response command by calling emberAfSendResponse().

10.2 ZCL Command Processing

When the Zigbee Application Framework receives a ZCL command, it is passed off for command processing inside the utility function `emberAfProcessMessage`, located within *app/framework/util/util.c*. The process message function parses the command and populates a local struct of the type `EmberAfClusterCommand`. Once this struct is populated, it is assigned to the global pointer `sli_zigbee_af_current_command` so that it is available to every function called during command processing.

`emberAfProcessMessage` first calls `emberAfPreCommandReceivedCallback` to give the application a chance to handle the command. If the command is a global command, it is passed to *process-global-message.c* for processing; otherwise, it is passed to *process-cluster-message.c* for processing.

Note: For more information on command processing flow, see the message flowcharts in section 5.7 Callback Flow for Message Processing. Also, for more information on ZCL command runtime subscription, refer to section 5.4 ZCL Command Handling Callbacks

10.2.1 app/framework/util/process-global-message.c

process-global-message.c handles all global commands, such as reading and writing attributes. Global commands do not currently have associated command callbacks the way cluster-specific commands do.

10.2.2 app/framework/util/process-cluster-message.c

process-cluster-message.c handles all cluster-specific commands and passes them on to software modules that have subscribed to a specific cluster using the `sl_zigbee_subscribe_to_zcl_commands()` API. The subscribed callback is passed the actual ZCL command in the form of an `EmberAfClusterCommand` struct. The *zap-cluster-command-parser.[c,h*] generated files provide command-specific structs and APIs to further parse the ZCL command into a specific ZCL command. For example, for the “stop” command provided by the “level control” cluster, the following struct contains the exact fields of such command:

```
    sl_zcl_level_control_cluster_stop_command_t cmd_data;
```

The following API can be invoked to parse out the specific ZCL command into the corresponding struct:

```
    zcl_decode_level_control_cluster_stop_command(cmd, &cmd_data);
```

Where `cmd` is a pointer to a `EmberAfClusterCommand` struct passed to the subscribed callback.

Note: Since the cluster-specific command callbacks are called within the command handling context, all of the metadata associated with any command handled in one of these callbacks is available from the global pointer `sli_zigbee_af_current_command`.

Always access the global pointer `sli_zigbee_af_current_command` by using the convenient macro provided in *app/framework/include/af.h* called `emberAfCurrentCommand()`.

10.3 Sending a Default Response

The Zigbee Application Framework does not automatically send a default response for command handled by the application. In order to improve system reliability and flexibility, Silicon Labs has handed all the default response handling over to the application. This means that, while you now have complete control over sending default responses for commands that you handle, you also are responsible for sending default responses for all those commands. A default response must be sent for any unicast message that does not have a specific response and is not itself a default response. For more information on when default response should and should not be sent, please refer to the Zigbee documentation.

The Zigbee-created components handle sending default responses for all the commands that they handle. Any commands that the components do not handle automatically return *EMBER_ZCL_STATUS_UNSUP_COMMAND*, or something like it. Your application needs to do the same for all the commands it handles that do not themselves have a specific command response.

Silicon Labs has created a default response API to make this is simple as possible. The `emberAfSendDefaultResponse` command takes two arguments: the current command, and the status byte. The current command can be retrieved from the Zigbee Application Framework using `emberAfCurrentCommand()`. The ZCL status bytes used for default response are enumerated in *app/framework/gen/enum.h*.

```
void emberAfSendDefaultResponse(EmberAfClusterCommand *cmd, EmberAfStatus status);
```

A typical use of this function looks like:

```
emberAfSendDefaultResponse( emberAfCurrentCommand(), EMBER_ZCL_STATUS_SUCCESS );
```

11 The Command Line Interface (CLI)

The CLI commands are generated in a project based on the set of ZCL clusters and software components selected in the project. To use the CLI functionality in a Zigbee application the following components must be installed in the project:

- Zigbee ZCL CLI
- Zigbee Core CLI

The Services->CLI: Command Line Interface component is also required for the CLI to function. However, it does not need to be enabled explicitly as it pulled as a dependency by the Zigbee CLI components.

Any software component may carry with it some CLI commands. Installing a component in the project makes its CLI commands available to the application.

You can also define your own CLI commands. See the Gecko Platform Command Line Interface documentation for more information.

12 The Debug Printing Interface

Debug printing in a Zigbee application is controlled by the **Debug Print** component. enable/disable debug printing for various code areas (*stack, core, application, zcl*).

The API for debug printing in the application code is the `sl_zigbee_app_debug_print(…)` API. This function accepts the standard `printf()` arguments and format flags. Settings are controlled through the *application* print area in the **Debug Print** component.

13 Multi-Network Support

Multi-network and multi-PAN features allow a device to operate on two Zigbee networks using the same radio. These Zigbee networks may have different security settings or network parameters, such as short ID, PAN ID, extended PAN ID, or radio power. The only parameter that stays the same on all networks is the node's EUI64. While the multi-network feature allows the two networks to be on different radio channels, the multi-PAN feature requires that this setting matches.

The EmberZNet SDK greatly simplifies network context maintenance in application callbacks and network specific stack status handlers. For more details on this and API descriptions, see *AN724: Designing for Multiple Networks on a Single Zigbee Chip.* This section discusses how the feature may be enabled and configured on a sample application.

13.1 Configuration

Multi-network / Multi-PAN functionality may be enabled by editing the Zigbee Device Config component. These are the high-level steps:

1. Find and click Configure on “Zigbee device config” component.
2. Enable the secondary network.
3. Select the device type and network security for the secondary network.
4. Select the default network. Default is set to primary. You can set this to secondary, if required.
5. Select the Tx power mode.
6. Make cluster and endpoint selections for each network using Zigbee Cluster Configurator.

By default, all endpoints are assigned to a network named “Primary” whose network index shows as 0. To assign endpoints to the secondary network, you will need to set the network index to the value 1. Note that each endpoint belongs to one network and its value must be unique across networks. Each network may contain multiple endpoints.

14 Sleepy Devices

14.1 Introduction

The Zigbee Application Framework contains support for sleepy end devices. A sleepy end device is a device on the Zigbee network that spends most of its life in a low-power mode and only wakes up the processor when it needs to do something specific such as to interpret a GPIO interrupt or poll its parent to see if there are any messages waiting for it on the network.

14.2 Polling

Sleepy end devices do not receive data directly from other devices on the network. Instead, they must poll their parent for data and receive the data from their parent. The parent acts as a surrogate for the sleepy device, staying awake and buffering messages while the child sleeps. As a result, the sleep/wake cycle of the sleepy end device is governed by two important timeouts on the Zigbee network: the APS retry timeout (7.8 seconds) and the End Device Poll timeout (defined by the parent defaults to 5 minutes). These two timeouts correspond to two polling intervals on the sleepy end device: the SHORT_POLL and the LONG_POLL intervals. These intervals are sometimes referred to as the “nap duration” and “hibernation duration” respectively. So, when a device is in a state where it is continually sending polls out on the SHORT_POLL interval, it is considered to be “napping,” due to the fact that it is continually waking up after a very short period to poll. When a device is sending out polls on the LONG_POLL interval, it is said to be “hibernating,” since it is sleeping for a longer interval.

When a device needs to be responsive to messages being sent to it from the network, it goes into a state where it polls its parent on the SHORT_POLL interval (napping). This ensures that any messages received by its parent will immediately be retrieved by the sleepy end device and processed. When the device no longer needs to be as responsive on the network, it returns to a state where it polls its parent on the LONG_POLL interval (hibernating) which ensures that the child will remain alive in its parent’s child table but will not be responsive to the network.

The time during which the sleepy end device is polling at an augmented rate based on the SHORT_POLL interval is referred to as the “Short Poll Mode,” “Fast Poll Mode,” or simply “Napping.” All these terms mean the same thing. The sleepy device is polling its parent faster than the 7.68 seconds allowed for an end devices parent to hold onto a message for the end device. Generally, the SHORT_POLL interval will be something less than one second to ensure that all messages sent to the parent are processed in an orderly fashion, because the parent is only required to hold onto a single message. If the messages are not retrieved from the parent quickly enough, they may be overwritten by other incoming messages for the same child or some other child. For more information on Fast Polling, see section 14.2.4 Forcing Fast Polling.

14.2.1 The SHORT_POLL Interval

The SHORT_POLL interval is the amount of time that an end device may wait before polling its parent when it is in the process of sending or receiving a message. This interval must be shorter than the Indirect Transmission Timeout (standardized at 7.68 seconds for Zigbee networks). This is because the end device must send an APS ACK back to the sending device before the sending device decides to resend the message. The result is that, in order for sleepy end devices to reliably communicate with other devices on the network, they must know when they are in the process of sending or receiving a message and must wake and poll their parent for data within the short poll interval until the message transaction is complete.

14.2.1.1 Setting at Compile Time

The SHORT_POLL interval is configurable in one-second increments and may be modified at compile-time by configuring the End device support component. This sets the define *EMBER_AF_PLUGIN_END_DEVICE_SUPPORT_SHORT_POLL_INTERVAL_SECONDS* in code.

14.2.1.2 Setting at Run Time

You can also modify the SHORT_POLL interval at runtime using the callbacks `emberAfSetShortPollIntervalMsCallback` or `emberAfSetShortPollIntervalQsCallback`.

14.2.2 The LONG_POLL Interval

The LONG_POLL interval is the amount of time that an end device may wait before polling its parent when it is otherwise inactive. This interval should, but is not required to, be shorter than the End Device Poll Timeout, which is the amount of time a parent device will wait to hear from its child before removing it from its child tables. The default end device poll timeout for Zigbee devices is set to 256 minutes.

Note: The Zigbee protocol does not offer a standard way to timeout entries in a child table. In place of this, several heuristic mechanisms exist for aging entries in a child table. For instance, if a parent hears a device that it thinks is its child interacting with another parent or being represented by another parent, it may remove the entry from its child table. Silicon Labs has developed a more deterministic mechanism for child aging called the End Device Poll Timeout. A parent expects that children will “check in” with their parents within the end device poll timeout. If they do not, it assumes that they have gone away and removes them from its child tables. The End Device Poll Timeout may be modified from its default value by configuring the Zigbee stack or leaf components, depending on the local device type.

The end device does not get to configure the end device poll timeout on its parent and there is no agreed upon protocol for communicating the End Device Poll Timeout value between parent and child. In place of this, Silicon Labs has configured an assumed end device poll timeout on both parent and child.

Depending on its sleep characteristics and battery life considerations, the child may wish to sleep past the assumed end device poll timeout. It is free to do this. However, if it does, it must repair the network connection by performing a network rejoin operation before interacting with the network again. Generally, a device that is likely to do this should check the state of the network when it wakes up to see if any repair is necessary before sending data. A sleepy device should never wake and assume that its parent is still there, unless it knows for certain that its parent is configured with a mutually agreed upon End Device Poll Timeout that it is obeying. For more information on the end device poll timeout see the configuration header file located at *stack/include/ember-configuration-defaults.h*.

14.2.2.1 Setting at Compile Time

The LONG_POLL interval is configurable in one-second increments and may be modified at compile-time by configuring the End device support component. This sets the define *EMBER_AF_PLUGIN_END_DEVICE_SUPPORT_LONG_POLL_INTERVAL_SECONDS* in code.

14.2.2.2 Setting at Run Time

You can modify the _LONG_POLL at runtime using the callbacks `emberAfSetLongPollIntervalMsCallback` or `emberAfSetLongPollIntervalQsCallback`.

14.2.3 Setting Values for the SHORT_POLL and LONG_POLL Intervals

The SHORT_POLL Interval should be less than the Indirect Transmission Timeout of the parent to prevent lost data/ACKs (< 7.8 seconds). The LONG_POLL Interval should be less than the End Device Poll Timeout of the parent (assuming the parent implements an End Device Poll Timeout) to prevent the parent from aging out the end device due to inactivity. By default, the Zigbee stack ships with a 256-minute End Device Poll Timeout. The manufacturer can change the End Device Poll Timeout as they wish. There is no standard way for routers to report their chosen End Device Poll Timeout to their children and it is not required for routers to implement child aging in the Zigbee specification. As a result, if a device implements a LONG_POLL_INTERVAL that is longer than 256 minutes, Silicon Labs recommends that the device check its network status before spontaneously sending messages through its parent. You want the device to make sure that the connection to the parent is up before it sends a message. If the network is not up, the device should perform a network rejoin to make sure that it has a parent before sending any message out over the air.

14.2.4 Forcing Fast Polling

Fast Polling is the state during which the stack actively polls its parent device faster than the 7.68 second child message timeout interval. The Zigbee Application Framework polls at the rate defined by the SHORT_POLL interval when it is in this mode. The Zigbee Application Framework automatically keeps the stack in the fast poll mode during the sending and ACKing of an APS message. When a device sends a message that is part of a series of application-level request/responses—as is the case in Smart Energy Registration—it must keep the device in fast poll mode until the entire transaction is completed.

The Zigbee Application Framework can ensure that the application stays in short poll mode for as long as the application requires by setting a flag in the `emberAfCurrentAppTasks` mask. To do this, create your own flag for the `emberAfCurrentAppTasks` that fits in with what is available according to the named masks in *app/framework/include/af.h*. The top 16 bits of the `emberAfCurrentAppTasks` mask are reserved for customer use. Once you have chosen a flag for your application, you may use the `emberAfAddToCurrentAppTasks` and `emberAfRemoveFromCurrentAppTasks` functions to add and remove your flag. If the flag is present in the `emberAfCurrentAppTasks` global bitmask, the application does not allow the stack to back into hibernation mode and the stack stays in short poll mode, during which it uses the SHORT_POLL interval to determine how quickly to poll the parent. The usage of this API is also documented in *app/framework/include/af.h*.

14.2.5 Using Fast Polling to Complete a Complex Transaction

Sometimes a sleepy device needs to stay in fast poll mode while sending a complex series of messages that constitute a complete application-level transaction with another device. The general strategy for this type of interaction on a sleepy end device is as follows:

1. Sleepy end device A needs to perform a series of messages with device B, called a transaction.
2. Sleepy end device A creates an event that will serve as a timeout for the application-level transaction, called the transaction timeout event.
3. Sleepy end device A starts the event and sends the first message to device B.
4. If the message is an APS message, sleepy end device A will automatically stay in short poll mode until the APS Ack comes back from the responding device.
5. If the message is a ZCL command, sleepy end device A will also automatically stay in short poll mode long enough to give device B a chance to send any application-level command response required by the ZCL
6. Sleepy end device A continues with its series of messages back and forth to device B until the whole transaction is complete.
7. When the final message of the transaction is completed with device B, Sleepy end device A removes the flag from `emberAfCurrentAppTasks` thereby allowing the device to naturally go back to using the hibernate or LONG_POLL period for sleeping.
8. If device A and B are not able to complete their transaction as expected, Sleepy End Device A removes the flag from `emberAfCurrentAppTasks` when the transaction timeout event set up in step 1 fires.

14.2.6 Difference in Polling on SoC and Host+NCP Models

The requirements of polling result in different sleep patterns for the System-On-Chip (SoC) and the Host + NCP models. In the Host + NCP model, it is the NCP that is responsible for polling at the SHORT_POLL and LONG_POLL intervals. The only responsibility of the host processor is to tell the NCP how frequently to poll. Other than that, the host may sleep indefinitely or until there is some internal event, a GPIO interrupt, or the NCP receives a message that it passes to the host for processing. Conversely, the SoC itself is responsible for polling its parent, so it must be sure to wake within the SHORT_POLL and LONG_POLL intervals in order to do so. The Zigbee Application Framework uses the internal event mechanism on the SoC to schedule polling. On the host, it sends a message down to the NCP to tell it when to poll.

14.3 Sleeping and the Event Mechanism

The Zigbee Application Framework automatically checks with the event mechanism to see when the next application event is scheduled. The Zigbee Application Framework never sleeps through an event. The sleep period is always shorter than the amount of time to the next application event within the framework. On the SoC, the amount of time that a device will sleep is generally governed by the SHORT_POLL and LONG_POLL intervals, because the polling event is also an event within the Zigbee Application Framework. On the host, the processor will attempt to sleep until the next application event.

14.3.1 Never Use Ticks on a Sleepy End Device

All application events should be scheduled through the event mechanism using either custom or cluster events on a sleepy end device. This is because the event mechanism provides a central repository for the sleep handling code so that it knows how long it can sleep. If you rely on the *emberAfMainTickCallback* to fire frequently enough to handle application events on your sleepy end device, you will be forced to wake the sleepy end device on an artificially short interval so that the *emberAfMainTickCallback* can be serviced.

14.4 End Device Parent Rediscovery

If an end device loses contact with its parent, it will automatically begin to rejoin the network either with the existing parent or a new parent by calling `emberAfStartMove`. The `emberAfStartMove` function schedules a “move” event in the Zigbee Application Framework’s event scheduling mechanism with the following characteristics:

- When the move event fires, the device calls `emberFindAndRejoinNetwork`.
- The move event is automatically rescheduled so that a network rejoin will be attempted every 10 seconds until EMBER_AF_REJOIN_ATTEMPTS_MAX is reached.
- If EMBER_AF_REJOIN_ATTEMPTS_MAX is set to 0xff (default) the rejoin will be attempted every 10 seconds until a network is found.
- The first attempt to rejoin the network is always performed with security on. Each subsequent attempt is performed with security off.

This orphan behavior can obviously have an impact on the life of a battery-powered device. By default, an end device will attempt a maximum of three rejoin attempts before giving up. This and other related configuration options may be found in the end device support config component.

14.5 Sleepy End Devices and the CLI

It is very difficult to interact with a sleepy end device on the CLI when it is sleeping. If you would like your sleepy end device to stay awake when it is not connected to a network, you can do so by enabling the "Stay awake when NOT joined" option in the Application Framework Common config component.

The other alternative is to provide a button Interrupt Service Routine (ISR) handler that toggles the device between a default wake and sleep state. A sample implementation may be enabled by enabling the “Use button to force wakeup or enable sleep” option in the Application Framework Common config component.

14.6 Processor Idling and the Zigbee Application Framework

The Zigbee Application Framework implements processor idling for sleepy devices. This feature augments power savings for sleepy devices by idling the processor during times that there are no events happening. This means that a sleepy device will not continually run through the application’s main loop when it is awake. Instead, the processor will idle until it receives an interrupt either from an external line or a scheduled event. Once each event has been handled, it is marked as ready to idle. The processor will then wait until the next internal or external interrupt before running through the application’s main loop again.

Some typical examples of when a sleepy device can save energy by idling include:

- While a packet—such as a data poll—is being transmitted from a sleepy device, the CPU is usually just waiting for the transmission to finish and can idle.
- While waiting for the crystal to stabilize, the CPU eventually runs out of initialization and calibration operations to do, so it can idle.

While waiting for the ACK to a transmitted packet. The radio still needs to be on in receive mode, so the processor cannot deep sleep but can safely idle.

15 Zigbee Application Framework Components

15.1 Introduction

The Zigbee Application Framework contains support for components. A component is an implementation of a piece of functionality within the framework. Components are installed and configured through the Component Editor. Zigbee Application Framework ships with default implementations of many of the ZCL clusters packaged as components. This section describes a subset of these components.

15.2 Over-the-Air Upgrade Components

The Over-the-Air (OTA) Bootload cluster is a large piece of functionality in the Smart Energy 1.1 specification. It involves a number of modules to support software implementations on different platforms and for both the client and server. This section details each of the different pieces and describes their function in the Zigbee Application Framework.

15.2.1 Architecture

This section explains the architecture of the cluster and where developer code fits into the Zigbee Application Framework.

The Zigbee OTA cluster provides a common way for all devices to have a manufacturer-independent method to upgrade devices in the field. The Zigbee OTA cluster only supports application bootloaders where a device has the capability to download and store the entire image in external storage while still running in the Zigbee network.

The Zigbee OTA cluster defines the protocol by which client devices query for new upgrade images and download the data, and how the server devices manage the downloads and determine when devices shall upgrade after downloading images.

Silicon Labs provides all the cluster code for both client and server to correctly process and respond to all Zigbee OTA messages. In addition, it provides code for managing the stored image(s) and bootloading the target chip.

A number of decisions have to be made about the architecture of the upgrade and how it will be handled. Below are several key questions to answer.

1. What external storage device will be used for the OTA upgrade image?
    1. Silicon Labs provides a few EEPROM driver implementations as well as a POSIX file system (for UART host only).
    2. If a different driver or method is desired, then this code must be provided.
2. Does a client device require multiple upgrade files to bootload?
    1. If so, the multiple upgrade files can be co-located within the same Zigbee OTA file transferred OTA. However, this requires a storage device that can hold all the upgrade files at the same time.
    2. The Zigbee OTA cluster also supports requesting multiple files, but the client must manage this.
3. How will upgrade files be labeled?
    1. Each OTA file has a manufacturer ID, an image type ID, and a version number. Zigbee assigns the value for the manufacturer ID, but the manufacturer controls the other two values, which can be set to whatever values the manufacturer wants. The choice of what values to use depends on the versioning scheme used by the developer and how products from the same manufacturer are differentiated.
4. Will image signing and verification be used by client devices?
    1. Although the choice to support the Zigbee OTA cluster is optional for SE devices, if devices do support the cluster, then manufacturers must digitally sign upgrade images and their devices must verify the authenticity and integrity of those images.
    2. Manufacturers that use image signing must obtain signing certificates and embed the EUI64s of allowed signers within the software so downloaded images can be validated.
5. How will bootloading be handled by clients?
    1. Bootloading is device specific, although Silicon Labs provides sample code to bootload both its SOC and NCP chips. But it is likely the developer will have to provide additional specific code to support their own device.
6. How will the server receive the images to be distributed to clients?
    1. The Zigbee implementation provides a POSIX server that can serve up OTA files that reside on a file system. If the server is an EEPROM-based system, then some other mechanism must be created to transfer the images to the server so they can be served to Zigbee OTA clients.

15.2.1.1 Generating Zigbee OTA Images

Silicon Labs provides a tool called Image-builder that can generate correctly formatted Zigbee OTA images. This tool takes in bootloader files (such as a GBL file) and generates the correct format according to the command-line input, as illustrated in the following figure. The tool can also sign the images using the Elliptic Curve Digital Signature Algorithm (ECDSA) signature algorithm as dictated by the Zigbee OTA cluster specification.

For more information on using Image-builder, see *AN716: Instructions for Using Image-Builder*.

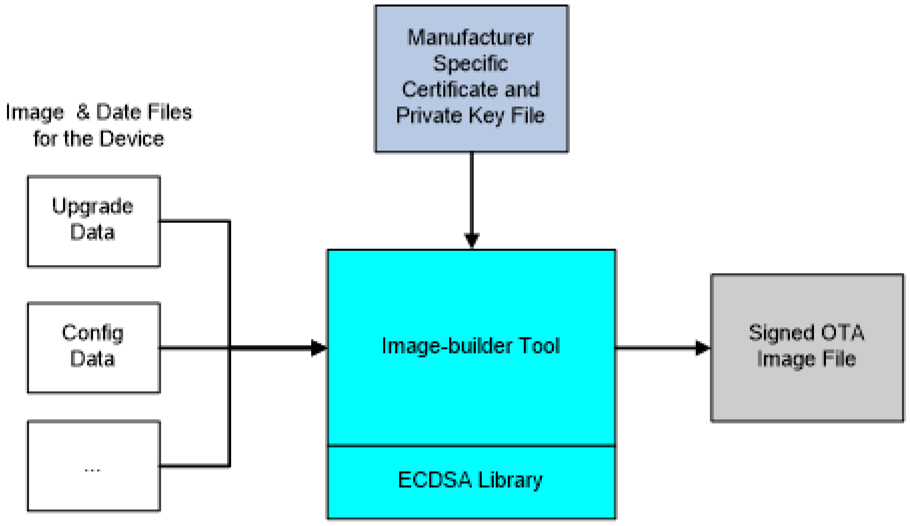

Manufacturer Specific Certificate and Private Key File
Image & Date Files for the Device
Upgrade Data
Config Data
...
Image-builder Tool
ECDSA Library
Signed OTA Image File

Figure 15.1. OTA Image Generation

15.2.1.2 Image Signing

The Zigbee SE Profile requires that OTA files be signed by the manufacturer. Downloaded files must be validated by the OTA client prior to installation. When images are signed, the signer's certificate is included automatically as a tag in the file and a signature tag is added as the last tag in the file.

The EUI of the authorized signing certificates must be embedded in the client's current software image so it can validate that only the certificates pertaining to the manufacturer of the device can sign update images.

For development and or test deployments that want to use signing and OTA images a test certificate can be used from the Certicom Test CA to sign images. Image-builder has a test certificate embedded in it for this purpose and by default Project Configurator includes the EUI of that test certificate as an authorized signer.

Note: For generation of production images to be shipped to deployed devices, it is highly recommended that manufacturers use their own certificates issued from the Certicom Production CA to sign images and specify only these EUIs as authorized signers.

The certificates and private keys used for signing are the same type as certificates and private keys used by SE devices. However, their use and storage should be handled differently. These are the differences:

1. Certificates and private keys used for signing should only be used for signing. They should never be put on devices as device-specific certificates and keys. This holds true regardless of whether the device is a test device or a production device.
2. The EUI used for the signing certificate should NOT be used for by any other device or for any other purpose. That EUI should NOT be part of a general pool of EUIs used for production devices.
3. It is recommended that at least three signing certificates with private keys be generated with three different EUIs. Multiple signing certificates allows for deprecating an expired or compromised private key.
4. Devices should be set up to accept all of those EUIs as authorized signers of images. If a single key or certificate is compromised, it can be deprecated through a software update and devices will not accept images signed by that entity. In that case, a new signing certificate should be created to replace the compromised one and subsequent software releases should set it up to be an authorized signer. In the interim, one of the other two alternative signing certificates can be used to sign software updates.
5. Signer private keys should be stored in a secure location with limited access.

6. Lastly, it should be noted that mixing production device certificates with a test certificate signer (and vice versa) does not work. In other words, if a device has a production certificate from the Certicom Production CA, then it can only validate images signed with a production certificate. Similarly, devices with test certificates can only accept signers that have certificates issued from the Certicom Test CA.

15.2.2 Component Architecture

A diagram of the architecture of the OTA components is shown in the following figure.

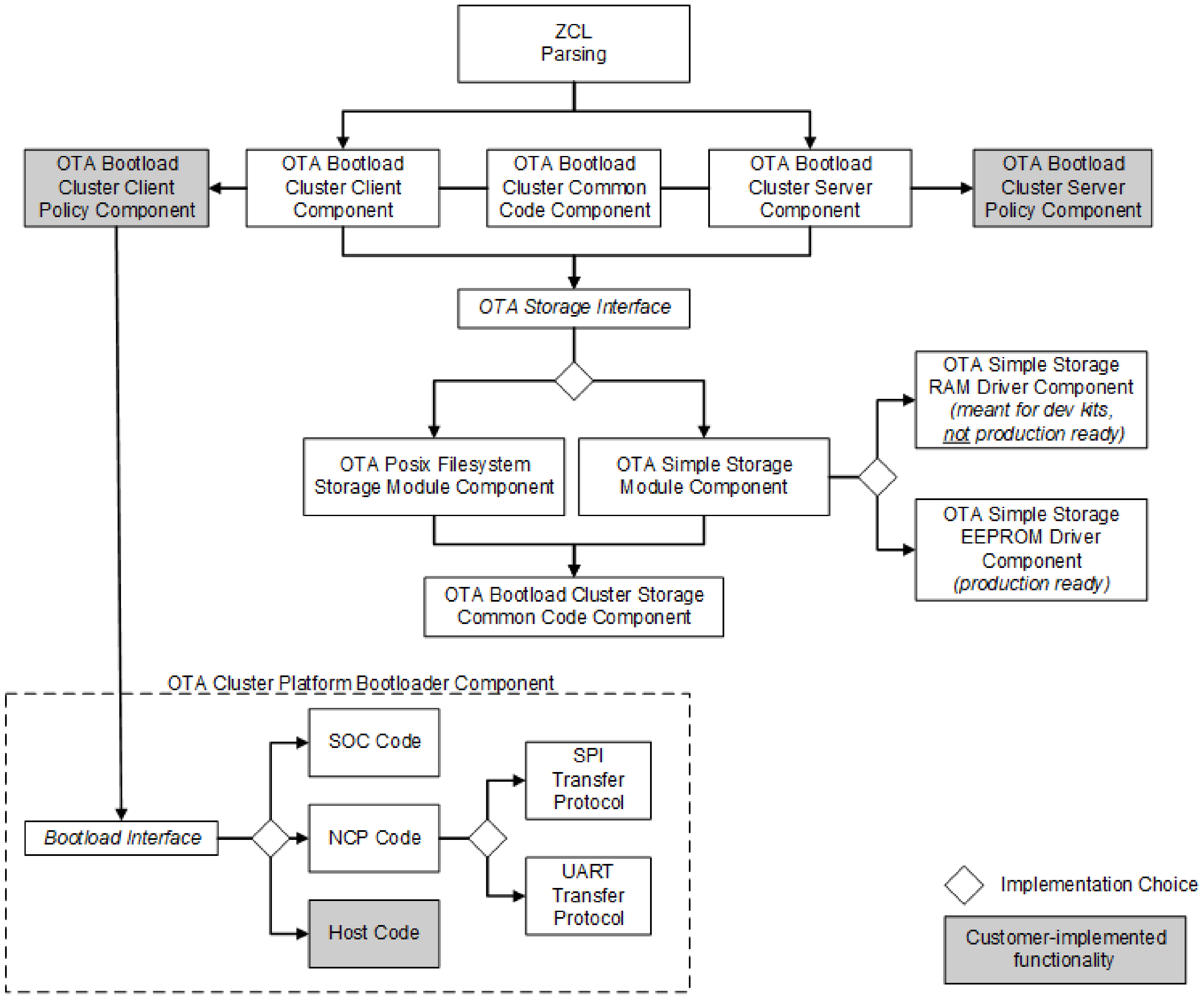

ZCL Parsing
OTA Bootload Cluster Client Policy Component
OTA Bootload Cluster Client Component
OTA Bootload Cluster Common Code Component
OTA Bootload Cluster Server Component
OTA Bootload Cluster Server Policy Component
OTA Storage Interface
OTA Simple Storage RAM Driver Component (meant for dev kits, not production ready)
OTA Posix Filesystem Storage Module Component
OTA Simple Storage Module Component
OTA Simple Storage EEPROM Driver Component (production ready)
OTA Bootload Cluster Storage Common Code Component
OTA Cluster Platform Bootloader Component
SOC Code
SPI Transfer Protocol
Bootload Interface
NCP Code
UART Transfer Protocol
Host Code
Implementation Choice
Customer-implemented functionality

Figure 15.2. OTA Component Architecture

15.2.3 ZCL Framework Core

This code is provided by the core Zigbee Application Framework and performs the basic parsing and verification of incoming and outgoing messages using the ZCL.

15.2.4 OTA Bootload Cluster Common Code Component

This component provides common code to the OTA client and server cluster components. It must be enabled if either the **OTA** Bootload Cluster Server Component or the OTA Bootload Cluster Client Component is enabled. This component has no configurable options.

15.2.5 OTA Bootload Cluster Server Component

The OTA Server cluster performs the message parsing of OTA Bootload cluster client commands sent to the server and generates server commands sent to the clients. It does not handle storage of the OTA files, but instead relies upon an external module for that support. Its role is simply to validate the incoming messages and generate the correct replies based on its own supported functionality and the OTA specification.

Silicon Labs provides a Zigbee Application Framework component that implements the server cluster.

Options	Description
Page Request Support	The OTA Server Cluster component can support the optional Page Request feature of the Zigbee OTA cluster. If this option is enabled, the server will answer page requests and send multiple blocks of the download image back to the client.

15.2.6 OTA Bootload Cluster Server Policy Component

This module defines how the OTA server reacts when it receives certain requests from the client. The server cluster code calls into this module to ask how certain operations should be handled. For example, when a client is finished downloading a file, it sends an *upgrade end request* to the server to ask when it can upgrade to the new image. The server cluster code parses the message and then calls into the server policy code to determine the answer.

Other examples of policies handled by this module include how to respond when a query for the *next* OTA image to download is received and how to respond when receiving an image block request.

This component has no configurable options.

15.2.7 OTA Bootload Cluster Client Component

The OTA client cluster performs the message parsing of OTA Bootload cluster server commands sent to the client and generation of client commands sent to the server. It does not handle storage of the OTA files, but instead relies upon an external module for that support. Its role is simply to validate the incoming messages and generate the correct replies based on its own supported functionality.

Silicon Labs provides a Zigbee Application Framework component that implements the client cluster. The component has optional support for the signature verification feature. When enabled, this checks the ECDSA signature on received OTA files before generating the upgrade end message sent back to the server.

Options	Description
Query OTA Server Delay (minutes)	How often the client queries the OTA server for a new upgrade image.
Download Delay (ms)	How often a new block of data (or page) is requested during a download by the client. A value of 0 means the client requests the blocks (or pages) as fast as the server responds.
Download Error Threshold	How many sequential errors cause a download to be cancelled.
Upgrade Wait Threshold	How many sequential, missed responses to an upgrade end request cause a download to be applied anyway.
Server Discovery Delay (minutes)	How often a client looks for an OTA server in the network when it did not successfully discover one. Once a client discovers the server, it remembers that server until it reboots.
Run Upgrade Delay Request (minutes)	How often the client will ask the server to apply a previously downloaded upgrade when the server has previously told the client to wait.

Options	Description
Use Page Request	Selecting this option causes the client device to use an OTA Page Request command to ask for a large block of data all at once, rather than use individual image block requests for each block. If the server does not support this optional feature, then the client falls back to using individual block requests.
Page Request Size	The size of the page to request from the server.
Page Request Timeout (seconds)	The length of time to wait for all blocks from a page request to come in. After this time has expired, missed packets are requested individually with image block requests.
Signature Verification Support	This requires all received images to be signed with an ECDSA signature and verifies the signature once the download has completed. If an image fails verification, it is discarded. This verification occurs prior to any custom verification that might verify the contents.
Verification Delay (ms)	This controls how often an ongoing verification process executes. When signature verification is enabled, this controls how often digest calculation is executed. Digest calculation can take quite a long time for an OTA image. Other processing for the system may be deemed more important and therefore Silicon Labs adds delays between calculations. This also controls how often custom verification written by the application developer is executed. A value of 0 means the calculations run to completion.
Image Signer EUI64 0	The big endian EUI64 address of a device authorized to sign OTA images for this client. A value of all 0s is ignored.
Image Signer EUI64 1	The big endian EUI64 address of a device authorized to sign OTA images for this client. A value of all 0s is ignored.
Image Signer EUI64 2	The big endian EUI64 address of a device authorized to sign OTA images for this client. A value of all 0s is ignored.

Note: The default value for the Image Signer EUI64 0 option is the EUI64 of the test certificate embedded within the Image-builder provided by Silicon Labs. Using this default will allow customers to test image signing and verification prior to obtaining production signing certificates from Certicom.

15.2.8 OTA Bootload Cluster Client Policy Component

This module controls the OTA cluster client's behavior. It dictates what image information it uses in the query, what custom verification of the image is done by the device, and what happens when the client receives a command to upgrade to the new image.

Silicon Labs provides a component that provides a simple implementation of the OTA client policy.

Note: The Manufacturer ID is not set in this component, but in the top tab of the Zigbee Cluster Configurator.

Options	Description
Image Type ID	The device's OTA image identifier used for querying the OTA server about the next image to use for an upgrade.
Firmware Version	The device's current firmware version used when querying the OTA server about the next image to use for an upgrade.
Hardware Version	Devices may have a hardware version that limits what images they can use. OTA images may be configured with minimum and maximum hardware versions on which they are supported. If the device is not restricted by hardware version, then this value should be 0xFFFF.
Perform EBL Verification (SOC only)	This option uses the application bootloader routines to verify the EBL image after signature verification passes.

15.2.9 OTA Storage Components

The OTA cluster requires a storage device for files received by the OTA clients or served up by the OTA server. This storage varies based on the device's hardware and design. Therefore, this functionality is separated from the core cluster code and accessed through a set of APIs. The interface supports managing multiple files, retrieving arbitrary blocks of data from the files, and performing basic validation on the file format.

Silicon Labs currently provides two main components that implement the OTA storage module, the **OTA Storage POSIX Filesystem** component and the **OTA Simple Storage** component.

15.2.9.1 OTA Storage POSIX File System Component

This implementation uses a POSIX file system as the storage module to store and retrieve data for OTA files. It can handle any number of files. This component is used with an EZSP-based platform (such as EFR32 NCP) where the host is connected to the NCP through UART. This component has no configurable options.

15.2.9.2 OTA Simple Storage Module Component

This implementation provides a simple storage module that stores only one file. It uses an OTA storage driver to perform the actual storage of the data in a hardware or software device accessible by the OTA cluster code. When enabled, the developer must also select either the **OTA Simple Storage RAM Driver Component** or the **OTA Simple Storage EEPROM Driver Component**.

This component can be used by either an EZSP- or an SOC-based platform. This component has no configurable options.

15.2.9.3 OTA Simple Storage RAM Driver Component

This driver provides a RAM storage device for storing files. It is intended only as a test implementation for development on WSTKs; it is not intended as production ready code. Prior to integrating external storage hardware into a device, this driver can be useful for examining the basic behavior of the OTA cluster. The storage device has a pre-built OTA image already in place that can be used for downloading but does not actually perform an upgrade. This component has no configurable options.

15.2.9.4 OTA Simple Storage EEPROM Driver Component

This driver uses the platform routines to read and write data from an EEPROM. For SOC platforms, this module handles the details of re-mapping the image so that it can be read by the bootloader. Existing bootloaders require that the GBL header be the first bytes at the top the storage device so the code must relocate the OTA header to another location while at the same time providing an interface to the storage code that accesses the OTA file in a linear manner.

The following figure illustrates a change in the OTA image on disk.

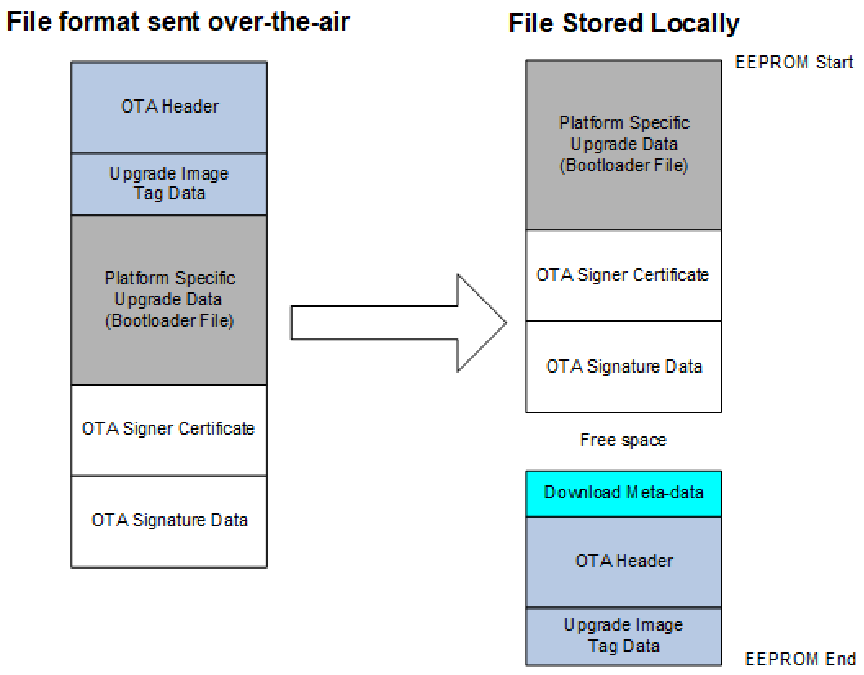


Figure 15.3. OTA Image Change

Options	Description
SOC Bootloading Support	This option enables bootloading support for SOC devices. When enabled, it will re-map the OTA image file so that the bootloader data is at the top of the EEPROM and therefore can be accessed by all existing Ember bootloaders. It requires that the bootloader portion of the image is the first TAG in the file. The OTA storage starting offset should be 0 when this is enabled.
Frequency for Saving Download Offset to Non-Volatile Memory (bytes)	How often the current download offset is stored to NVM, in bytes. If set to 0, it will always be written to NVM.
OTA Storage Start Offset	The starting offset for the OTA image storage location in the NVM.
OTA Storage End Offset	The last offset for the OTA image storage location in the NVM.
EEPROM Device Read-modify-write Support	This checkbox indicates whether the underlying EEPROM storage driver has support for read-modify-write, where a portion of a page of flash can be rewritten without erasing the entire page. If the driver requires a page erase before writing any data, this box should not be selected. Before EmberZNet 4.6.2 read-modify-write support was required by the underlying flash driver. EmberZNet 4.6.2 introduced the ability to use parts where a page-erase is required. When designing software for the development boards this checkbox should remain selected because the EEPROM parts require read-modify-write support.

15.2.9.5 OTA Bootload Cluster Storage Common Code Component

This component provides code common to all the OTA storage components and must be enabled when one of those components is enabled. This component has no configurable options.

15.2.10 OTA Cluster Platform Bootloader Component

When the client has a completed file downloaded and ready to upgrade, it waits for a command from the server to apply the upgrade. Upon receipt of the command to upgrade, the OTA client cluster code calls into the OTA client policy code to perform the next steps to apply the upgrade.

Silicon Labs provides a single component to handle bootloading. The behavior differs depending on the platform on which it is being used. The OTA Client Policy component calls into this component to perform the actual bootloading.

For the SoC, the bootload code simply calls the platform routine to execute the application bootloader. The application bootloader then reads from the data stored in external EEPROM, copies that data into the chip's internal flash, and then reboots.

For the NCP, Silicon Labs provides an implementation that bootloads the NCP through serial UART or SPI bus. This implementation works only with the Ember NCP bootloader provided as part of the EZSP NCP firmware delivery. The implementation executes the bootloader on the NCP, transfers the file from the storage device on the host to the NCP by XModem, then reboots the NCP.

For the host, developers are expected to write their own code for bootloading a host system connected to an NCP.

15.2.11 OTA Cluster Command Line Interface

15.2.11.1 Client Commands

Table 15-1. OTA Cluster Client Commands

Command	Description
zcl ota client printImages	Prints all images that are stored in the OTA storage module along with their index.
zcl ota client info	Prints the Manufacturer ID, Image Type ID, and Version information that are used when a query next image is sent to the server by the client.
zcl ota client status	Prints information on the current state of the OTA client download.
zcl ota client verify <index>	Performs signature verification on the image at the specified index.
zcl ota client bootload <index>	Bootloads the image at the specified index by calling the OTA bootload callback.
zcl ota client delete <index>	Deletes the image at the specified index from the OTA storage device.
zcl ota client start	Starts the OTA client state machine. The state machine discovers the OTA server, queries for new images, download the images, and waits for the server command to upgrade.
zcl ota client stop	Stops the OTA client state machine.
zcl ota client page-request <boolean>	Dynamically enables or disables the use of page request if the client turned on support in Project Configurator. By default, if the client enabled page request support in Project Configurator, then the client uses the page request command when downloading a file.
zcl ota client block-test	Test harness command. Sends an invalid block request to the client's previously discovered OTA server to verify that the server sends back the correct command.

15.2.11.2 Server Commands

Table 15-2. OTA Cluster Server Commands

Command	Description
zcl ota server printImages	Prints all images that are stored in the OTA storage module along with their index.
zcl ota server policy print	Prints the policies used by the OTA Server Policy component.
zcl ota server delete <index>	Deletes the image at the specified index from the OTA storage device.
zcl ota server policy query <int>	Sets the policy used by the OTA Server Policy component when it receives a query request from the client. The policy values are: 0: Upgrade if server has newer (default). 1: Downgrade if server has older. 2: Reinstall if server has same. 3: No next version (no *next* image is available for download).

Command	Description
zcl ota server policy blockRequest <int>	Sets the policy used by the OTA Server Policy component when it receives an image block request. The policy values are: 0: Send block (default) 1: Delay download once for 2 minutes 2: Always abort download after first block
zcl ota server policy upgrade <int>	Sets the policy used by the OTA Server Policy component when it receives an upgrade end request. The policy values are: 0: Upgrade Now (default) 1: Upgrade in 2 minutes 2: Ask me later to upgrade
zcl ota server notify <dest> <payload type> <jitter> <manuf-id> <device-id> <version>	This command sends an OTA Image Notify message to the specified destination indicating a new version of an image is available for download. The payload type field values are: 0: Include only jitter field 1: Include jitter and manuf-id 2: Include jitter, manuf-id, and device-id 3: Include jitter, manuf-id, device-id, and version All fields in the CLI command must be specified. However, if the payload type is less than 3, those values will be ignored and not included in the message.
zcl ota server page-req-miss <modulus>	Test harness command. Sets a module’s value that tells the OTA server to artificially skip certain image block responses sent in response to an image page request. This simulates missed blocks that the client will have to request later after the page request has completed. If the number of the block sent by the server is a multiple of the modulus value, then it will be skipped.

15.2.12 OTA Client State Machine

The following figure illustrates how the OTA Bootload Cluster client component code will behave from start to finish.

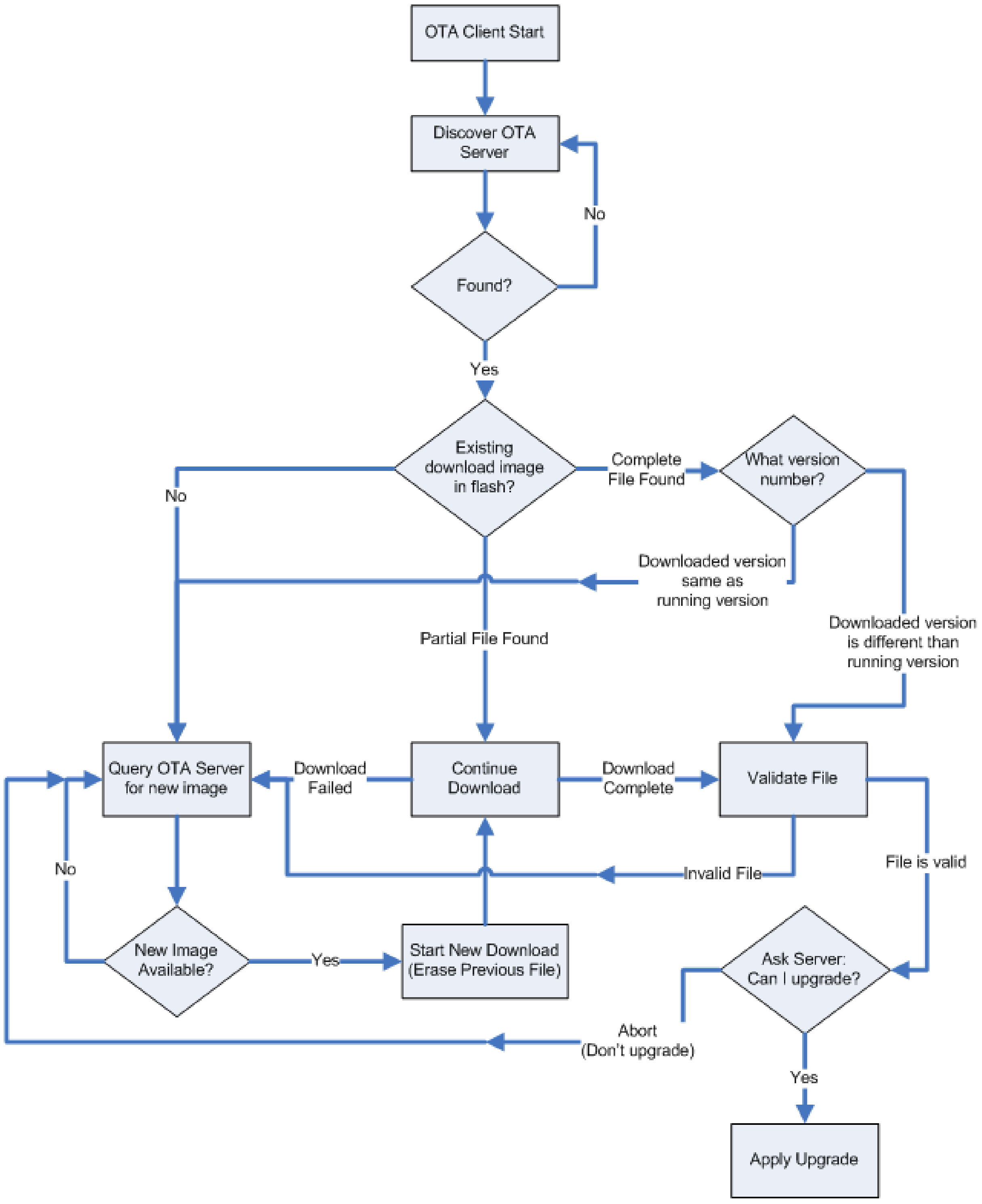


Figure 15.4. OTA Bootload Cluster Client Component Behavior

15.2.13 Example Client and Server Setup

A separate application note (*AN1384: Over-the-Air Bootload Server and Client Setup for Zigbee SDK 7.0 and Higher*) describes a complete client and server setup using plugins and Silicon Labs development kits.

15.3 Reporting Component

ZCL reporting can be setup on a device when the device is required to periodically send out reports. ZCL reports rely on bindings. Each report is an asynchronous message sent out from the reporting device, when a local ZCL attribute has changed, to corresponding entries in the binding table. Either the node sending the reports, the node receiving the reports, or another third-party configuration device may create the binding table entry(s) on the reporting node. This component supports both requesting reports from another device and sending out attribute reports when the device has been configured to do so. If the application will receive reports from multiple sources, the device should be configured as a concentrator.

15.3.1 Reporting Command Line Interface

The Zigbee Application Framework provides CLI commands for creating and managing reporting table entries directly on the device, requesting reports from another device, and configuring device to send out reports from another device.

15.3.1.1 Local Commands

- `plugin reporting print`: Print the report table.
- `plugin reporting clear`: Print the report table.
- `plugin reporting remove [index:1]`: Remove an entry from the report table.
- `index`: Index of the report to be removed (1 byte).
- `plugin reporting add [endpoint:1] [clusterId:2] [attributeId:2] [mask:1] [minInterval:2] [maxInterval:2] [reportableChange:4]`: Add a new entry to the report table.
    - `endpoint`: Local endpoint from which the attribute is reported (1 byte).
    - `clusterId`: Cluster where the attribute is located (2 bytes).
    - `attributeId`: ID of the attribute being reported (2 bytes).
    - `mask`: 0 for client-side attributes or 1 for server-side attributes (1 byte).
    - `minInterval`: Minimum reporting interval, measured in seconds (2 bytes).
    - `maxInterval`: Maximum reporting interval, measured in seconds (2 bytes).
    - `reportableChange`: Minimum change to the attribute that will result in a report being sent (4 bytes).

15.3.1.2 Remote Commands

- `zcl global report [endpoint:1] [clusterId:2] [attributeId:2] [direction:1]`: Creates a report with the specified cluster, attribute, and server/client direction.
- `endpoint`: Source endpoint ID to read from (2 bytes).
- `clusterId`: Cluster ID to read from (2 bytes).
- `attributeId`: Attribute ID to read from (2 bytes).
- `direction`: 0 for client-to-server, 1 for server-to-client (1 byte).
- `zcl global report-read [cluster:2] [attributeId:2] [direction:1]`: Creates a global read reporting command for the associated cluster, attribute, and server/client direction.
    - `cluster`: Cluster ID to read from (2 bytes).
    - `attributeId`: Attribute ID to read from (2 bytes).
    - `direction`: 0 for client-to-server, 1 for server-to-client (1 byte).

- `zcl global send-me-a-report [cluster:2] [attributeId:2] [dataType:1] [minReportTime:2] [maxReportTime:2] [reportableChange:-2147483648]`: creates a global send me a report command for the associated values.
  - `cluster`: Cluster ID of the requested report (2 bytes).
  - `attributeId` : Attribute ID for requested report (2 bytes).
  - `datatype`: Zigbee type value for the requested report (1 byte).
  - `minReportTime`: Minimum number of seconds between reports (2 bytes).
  - `maxReportTime`: Maximum number of seconds between reports (2 bytes).
  - `reportableChange`: Amount of change to trigger a report.
- `zcl global expect-report-from-me [cluster:2] [attributeId:2] [timeout:2]`: Create an expect-report-from-me message with associated values.
  - `cluster`: Cluster ID of the requested report (2 bytes).
  - `attributeid`: Attribute ID for requested report (2 bytes).
  - `timeout`: maximum amount of time between reports.

15.3.2 Reporting Connection Setup through CLI

The following CLI example assumes these application configurations:

- The report sender application should implement the Basic Cluster on endpoint 6.
- The report receiver application should implement the Basic Cluster on endpoint 1.
- Both applications should have debugging messages turned on. It is also assumed that both devices have joined the same network with the report sender node as the creator of the network.

1. Clear all bindings on the sender node since reports are sent via bindings.

```
report_sender_cli> option binding-table clear
```

2. Request reports of the application version (cluster 0x0000, attribute 0x0001) of the sender to receiver node by receiving node.

```
report_receiver_cli> zcl global send-me-a-report 0x0000 0x0001 0x20 10 20 {00}
report_receiver_cli> send 0 1 6
```

3. Following outputs should be observed:

```
report_sender_cli> CFG_RPT: (Basic) - direction:00, attr:0000  type:20, min:000A, max:0014
change:00
report_receiver_cli> CFG_RPT_RESP: (BASIC) – status: 00
```

4. After successfully send the report request (status – 00), an actual report can be read by the receiver node using following command:

```
report_receiver_cli> zcl global report-read 0x0000 0x0000 0x00
report_receiver_cli> send 0 1 6
```

5. Following outputs should be observed:

```
report_receiver_cli> READ_RPT_CFG_RESP: (Basic) - status:00, direction:00, attr:0000  type:20,
min:000A, max:0014  change:00
```

6. Find node field ID or IEEEAddr from receiver node.

```
report_receiver_cli> info
```

7. Create binding on sending node to start sending reports to the receiver.

```
report_sender_cli> option binding-table set 0 0x0000 0x06 0x01 {EUI64 node ID from previous step}
```

8. Following outputs should be observed:

```
"set bind 0: 0x00"
```

9. The receiver node should start getting reports as follow:

```
report_receiver_cli> RPT_ATTR: (Basic) - attr:0000  type:20, val:01
```

10. Cancel report (by setting the maximum interval to 0xFFFF)

```
report_receiver_cli> zcl global send-me-a-report 0x0000 0x0000 0x20 0x0000 0xFFFF {00}
report_receiver_cli> send 0 1 6
```

11. Following outputs should be observed:

```
report_sender_cli>  CFG_RPT:  (Basic)  -  direction:00,  attr:0000   type:20,  min:0000,  max:FFFF
change:00
report_receiver_cli> CFG_RPT_RESP: (Basic) - status: 00
```

15.3.3 Reporting for External Attributes

The Zigbee Application Framework automatically notifies the component whenever attributes that it manages are changed. Customers who use external attributes must notify the Reporting component when those attributes change. Failure to notify the component will result in incorrect reporting behavior. Any applications that will be reporting external attributes must call `emberAfReportingAttributeChangeCallback` whenever external attributes change.

16 Extending the Zigbee Cluster Library

16.1 Steps for Adding Custom Clusters and Commands Overview

These are the high-level steps for adding custom clusters and commands:

1. Create an XML file with custom cluster and command definitions, using *app/zcl/sample-extensions.xml* as a template; put the XML file in your project directory.
2. In the Zigbee Cluster Configurator in the top bar click **ZCL EXTENSIONS…** and select the XML file from step 1.
3. The custom clusters should now be selectable in the Zigbee Cluster Configurator GUI along with the standard clusters. The custom clusters will appear under the domain name specified in the XML file—for example, <*domain name="Ember"/*>.
4. Implement custom cluster callbacks the same way as ZCL Command Handling callbacks. See section 6.4 ZCL Command Handling Callbacks for detailed instructions.

16.2 Manufacturer-Specific Commands and Clusters

Developers may extend the Zigbee application layer using any of the following techniques:

- Private Profile: The profile ID is a two-byte value passed in Zigbee messages in the Zigbee APS frame. For two Zigbee devices to interact at the application layer, they must have the same profile ID. If they do not, they will drop each other's messages. A private profile is used to completely protect all interaction within a given system. If you are planning to use Zigbee for your network and link layers but in other respects are planning to have a closed system, you may wish to create a private Zigbee Profile. If you use a private profile, your devices will not be interoperable with any other Zigbee devices using other profiles.
- Manufacturer-Specific Clusters: Any clusters with cluster IDs in the range 0xfc00 – 0xffff are considered manufacturer-specific and must have an associated two-byte manufacturer code. All commands and attributes within a manufacturer-specific cluster are also considered manufacturer-specific.

  Example: In the *sample-extensions.xml* file included with the Zigbee Application Framework, Silicon Labs has defined a sample manufacturer-specific cluster with Cluster ID 0xfc00 and manufacturer code 0x1002 (Silicon Labs' manufacturer code).
- Manufacturer-Specific Commands: You can augment a standard Zigbee cluster by adding manufacturer-specific commands to that cluster. Manufacturer-specific commands within a standard Zigbee cluster may use the entire range of command IDs 0x00 – 0xff. A two-byte manufacturing code must be provided for the manufacturer-specific command so that the command can be distinguished from the standard Zigbee commands in that cluster.

  Example: In the *sample-extensions.xml file* included with the application framework, Silicon Labs has defined three commands to extend the On/Off cluster: OffWithTransition, OnWithTransition, and ToggleWithTransition. These commands share the same command IDs as the standard Off, On, and Toggle commands in that cluster. However, they also include the manufacturer code 0x1002 indicating that they are Silicon Labs' manufacturer-specific commands.
- Manufacturer-Specific Attributes: Standard Zigbee clusters can be extended by adding manufacturer-specific attributes to your application. Manufacturer-specific attributes within a standard Zigbee cluster may use the entire attribute ID address space from 0x0000 to 0xffff. A two-byte manufacturer code must be included for each manufacturer-specific attribute so that it can be distinguished from non-manufacturer-specific attributes.

  Example: In the *sample-extensions.xml* file included with the Zigbee Application Framework, Silicon Labs has defined a single attribute Transition Time which shares the same attribute ID with the on/off state in the on/off cluster 0x0000. However, the transition time attribute also contains the manufacturer code 0x1002 indicating that it is Silicon Labs' manufacturer-specific attribute.

Note: Silicon Labs' manufacturer code 0x1002 is defined by the Connectivity Standards Alliance and is included in the Manufacturer Code database (Zigbee document #053874). Manufacturer codes are required for the implementation of manufacturer-specific clusters, attributes, and commands. Unique manufacturer codes are provided by the Connectivity Standards Alliance for each requesting organization. To get a manufacturer code for your organization contact the Connectivity Standards Alliance at https://csa-iot.org/.

16.3 Limitations to Consider

There are two notable limitations to consider when extending the Zigbee Application Framework with manufacturer-specific clusters, attributes, and commands:

- All cluster IDs including those of manufacturer-specific clusters MUST be unique within a single device. The Zigbee Application Framework does not currently support overlapping manufacturer-specific cluster IDs within a single device. In other words, you cannot implement cluster 0xFC00 with manufacturer code 0xFEED AND cluster 0xFC00 with manufacturer code 0xBEEF on the SAME device. The Zigbee Application Framework assumes that ALL cluster IDs are unique regardless of the manufacturer code associated with them.
- All attribute and command IDs within a manufacturer-specific cluster MUST be unique and are assumed to have the same manufacturer code as the cluster they are in. The Zigbee protocol does not support overlapping manufacturer-specific attributes or command IDs (with different manufacturer codes) WITHIN a manufacturer-specific cluster. The reason is simply that only a single manufacturer code is passed in the Zigbee application header. If the cluster addressed is in the manufacturer-specific range 0xFC00 – 0xFFFF, then the manufacturer code is assumed to apply to the cluster. This makes it impossible to address, for instance, Attribute 0x0000 with manufacturer code 0xFEED inside cluster 0x0000 with manufacturer code 0xBEEF. The Zigbee Application Framework does not even bother to store individual manufacturer codes for attributes within a manufacturer-specific cluster because the manufacturer code of the cluster is assumed to apply to all the attributes within it.

16.4 Defining ZCL Extensions within the Zigbee Application Framework and Project Configurator

The entire ZCL is defined in XML format in the */SiliconLabs/SimplicityStudio/<version>/developer/sdks/gecko_sdk_suite/<version>/app/zcl* directory. In addition to expected XML files such as *general.xml* or *ha.xml* that describe the clusters, commands and attributes associated with standard ZCL used by the Zigbee Application Framework, there is a sample extension file called, unsurprisingly, *sample-extensions.xml*. This XML file contains several sample Zigbee extensions including a custom cluster, custom attributes added to the on/off cluster, and custom commands added to the on/off cluster.

To extend the ZCL, you must create a similar extension file for your extensions and load them in the Zigbee Cluster Configurator as described in 16.1 Steps for Adding Custom Clusters and Commands Overview. Additional documentation about extending the Zigbee Application Framework is included in the *sample-extensions.xml* file.

Note: Any multi-byte numeric constant values specified in the XML file should specify the full number of digits as hexadecimal, such as "0x000000000000" (for an int48u) rather than simply "0x00" or "0". This ensures that the proper default value will be added to the GENERATED_DEFAULTS define during generation.

16.5 Manufacturer-Specific Attribute APIs

Some APIs in Zigbee Application Framework used to interact with attributes have been modified to take a manufacturer code as an argument.

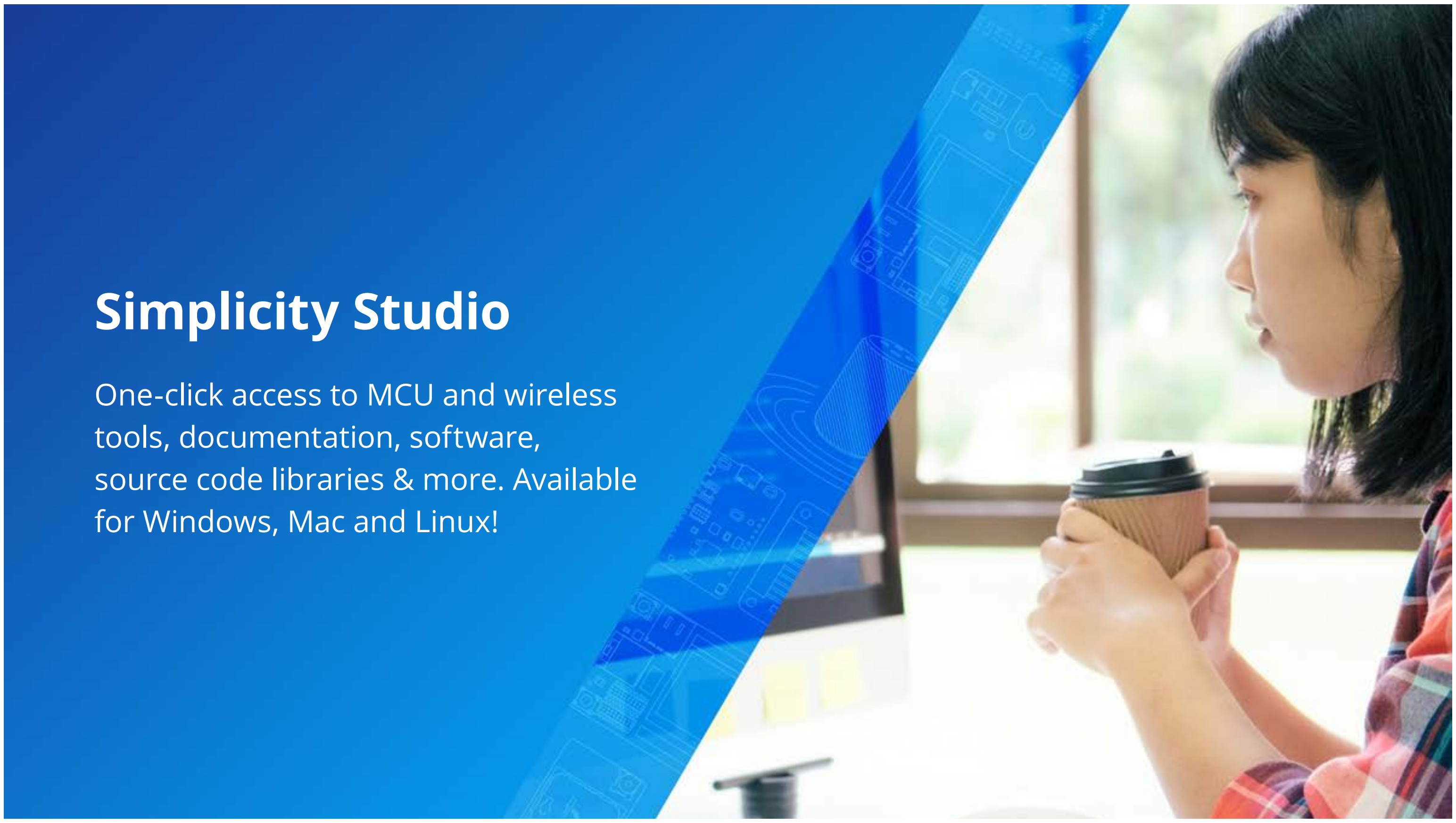
16.5.1 Attribute Read and Write

All of the read and write attribute functions have additional functions that take a manufacturer code along with the rest of the attribute-addressing information. When you read and write to a manufacturer-specific attribute, you must supply the manufacturer code for the attribute you wish to read or write so that it can be found in the attribute table. For example, you may read a standard Zigbee attribute using the function `emberAfReadServerAttribute`. However, if you call this function for a manufacturer-specific attribute no manufacturer Code argument allows you to properly identify your manufacturer-specific attribute, so the read will fail. If you wish to read a manufacturer-specific attribute, you must use the manufacturer-specific functions `emberAfReadManufacturerSpecificServerAttribute` and `emberAfReadManufacturerSpecificClientAttribute`. Both functions take a manufacturer code, which they pass on to the general function `emberAfReadOrUpdateAttribute`.

Separating the manufacturer-specific APIs into their own interface eliminates the need for code that is non-manufacturer-specific to pass around false manufacturer codes. This would be a waste of code space given the large number of attribute interactions that exist in the application framework.

16.5.1.1 Attribute Changed Callbacks

Silicon Labs has also added manufacturer-specific attribute changed callbacks into the Zigbee Application Framework so that standard attribute callbacks do not need to waste code space checking a non-existent manufacturer code.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