Developing Zigbee® smart energy applications on STM32WB Series

Introduction

This application note gives a global description of Zigbee® smart energy. It gives some hints on how to build Zigbee® smart energy applications on STM32WB Series microcontrollers and it covers as well sub-GHz operation and LBT topics.

STM32WB can address on 2.4 GHz major smart energy features like for instance metering device.

STM32WB is not necessarily targeting full energy service interface (ESI) device since it may request too many or unsupported resources like dual radio support for instance (STM32WB does not support sub-GHz operation).

1 General information

This document applies to the STM32WB Series dual-core Arm®-based microcontrollers.

Note: Arm is a registered trademark of Arm Limited (or its subsidiaries) in the US and/or elsewhere.

1.1 Acronyms and definitions

Table 1. Acronyms and definitions

Acronym	Definition
AFA	Adaptive frequency agibility
BEIS	Business energy and industrial energy
BOMD	Battery operated mirrored device
BSI	British standards institute
CBKE	Certificate based key establishment
CHTS	Communications hub technical specification
CPA	Commercial product assurance
DRLC	Demand response and load control
ESI	Energy service interface
GBCS	Great Britain companion specification
GSME	Gas meter
HA	Home automation
HAN	Home area network
IHD	In-home display
LBT	Listen before talk
MISRA	Motor industry software reliability association
NOC	network operations center
PCT	Programmable communicating thermostat
RIB	Residential incline block
TOU	Time of use
TSCO	Trust center swap
ZSE	Zigbee smart energy

1.2 Reference documents

1.2.1 Smart energy 1.4

- [1] 07-5356-21 Zigbee Smart Energy Standard Version 1.4
- [2] 07-5384-23 Zigbee Smart Energy Test Specification Version 1.4
- [3] 07-5390-10 Zigbee Smart Energy PICS (Pro-Forma)
- [4] Zigbee Smart Energy 1.4 Specification Errata
- [5] Zigbee Smart Energy 1.4 Test Specification Errata

- [6] Zigbee Smart Energy 1.4 PICS Errata
- [7] 17-05022-009 Zigbee Smart Energy Standard Test House Notifications for Versions 1.1b, 1.2b and 1.4

1.2.2 Smart energy 1.1b

Usually following the approval of a new version of a Zigbee specification, and once Test Houses are open for certification of the new version, the previous version enters a 6-month sunset period. During the sunset period devices can be certified under either version of the specification.

Even though versions past 1.1b have been approved, Smart Energy 1.1b is widely used in the North American market. As a result, in October 2017 the Zigbee Alliance board approved a 5-year extension for certification of Smart Energy 1.1b devices allowing certifications of both new and existing products under Smart Energy until 8 December 2022.

- [8] 07-5356-18 Smart Energy 1.1b Standard
- [9] 07-5384-20 Smart Energy 1.1b Test Specification
- [10] 07-5390-07 Smart Energy 1.1b PICS (Pro-Forma)

1.2.3 Zigbee PRO R22 - 2017

- [11] 05-3474-22 Zigbee Specification
- [12] 07-5035-08 Zigbee Compliant Platform Test Specification
- [13] 08-0006-07 2015 Layer PICS and Stack Profiles (Pro-Forma)
- [14] R22 Errata
- [15] IEEE 802.15.4-2015
- [16] 14-0332-02 Zigbee IEEE 802.15.4 PHY/MAC Test Plan Version 2.0 1.4.

1.2.4 ZCL

Just as ZSE 1.4 is not Zigbee 3.0 compliant, it is important to note that ZSE sometimes relies on ZCL 4 even though subsequent versions of ZCL have been approved and are in use for Zigbee 3.0.

- [17] 07-5123-04 ZigBee Cluster Library, Revision 4
- [18] 05-5123-07 Zigbee Cluster Library, Revision 7

1.2.5 OTA

The OTA used for smart energy is slightly different from the Zigbee 3.0 version. When certifying OTA for smart energy applications these documents are used instead of the Zigbee 3.0 documents.

- [19] 16-05028-001 ZCL Chapter 11 OTA
- [20] 09-5473-09 OTA Cluster Test Specification
- [21] 09-5284-10 OTA Cluster PICS (Pro-Forma)

1.2.6 Relationship between smart energy and other Zigbee® specifications

In the early stages of Zigbee, as new application areas were adopted such as home automation, commercial building, retail, telecom, the initial approach was to divide the new application areas into profiles, each with a unique Profile ID. This approach proved problematic as many practical applications span profiles. As a result, when Zigbee 3.0 was developed, it did away with profiles, using the home automation (HA) profile ID 0x0104 for all profiles except smart energy, which retained the original profile ID 0x0109. The strict security requirements of smart energy, specifically authentication using install codes and ECC certificates in CBKE as well as ECDSA signed images for OTA firmware updates are some of the main reasons why it could not be incorporated into Zigbee 3.0. The integration of smart energy is ongoing, and a future smart energy release will likely eliminate the remaining difference. However as of smart energy 1.4 and Zigbee 3.0 as noted, differences remain in security, OTA, and the profile ID. See the below document:

- [22] ETSI EN 300-220

2 Smart energy overview

Smart energy is one of the primary Zigbee applications. Smart energy is sometimes referred to as smart metering, and while it includes electrical, gas, and water metering, smart energy also includes provisions for:

- Scheduling and load control
- Pricing and payment (Including in-home or "in-premise" payment terminals)
- Customer display units
- Electric vehicle management
- Solar micro-generation (Net-metering)
- Many other features beyond simple metering

Smart energy is part of a global migration by utility providers to intelligent infrastructure, a key component of which is the Smart Grid. A Smart Grid has many components, ranging from generation and distribution to use by the end consumer.

Zigbee smart energy (ZSE) only concerns communication within end-user homes or businesses, a domain referred to as a home area network (HAN). When the end consumers are located in close proximity, HAN physically overlaps. However, for security reasons each HAN is unique, and messages within a HAN are securely encrypted to render communication impossible between overlapping HANs.

Zigbee is a flexible mesh networking technology. However, for security reasons when Zigbee is used in smart energy deployments, a star network topology is used. At the center of the star topology is the Zigbee coordinator or Energy Services Interface (ESI), which in some jurisdictions is referred to as a comms hub. In addition to forming the network and acting as the Zigbee Trust Center, the ESI also maintains a non-Zigbee connection known as a back- haul network. This back-haul network is connected to a network operations center (NOC) responsible for managing communication with each individual customer premise or HAN. Depending on the jurisdiction the NOC may be owned by the utility or a third party.

In a few instances the Zigbee smart energy specification assumes the existence of a back-haul network. Back-haul network communication protocols are specified by external regulatory bodies and outside the scope of the Zigbee specifications. There are often significant differences between back-haul networks used in different jurisdictions, and for this reason special attention must be given to the regulatory environment of the intended deployment zone.

Utilities are regulated by regional governments, which in turn put governmental bodies in place to mandate, specify, regulate, and certify the smart energy devices deployed by the utilities. While these governmental bodies have had a significant impact on the requirements that lead to the development of Zigbee smart energy, these agencies did not directly participate in the development of smart energy specifications. Zigbee smart energy is designed as a global standard, independent of any others jurisdiction. While in some locations governmental bodies have refined, extended, or restricted certain aspects of the Zigbee smart energy specification (for instance the UK Government has published the Great Britain Companion Specification (GBCS)), the Zigbee smart energy specification specifies wireless network operation within the HAN.

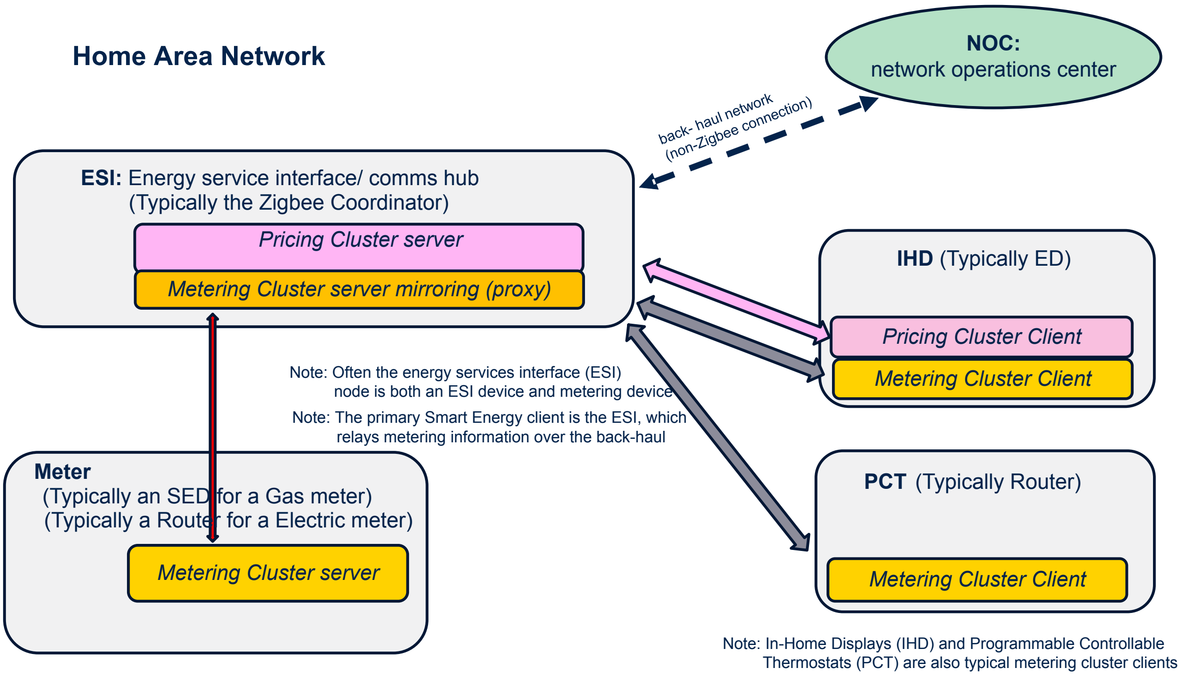
STM32WB Zigbee solution provides the main foundation on which smart energy applications can be built and certified for operation in the smart energy HANs. Some jurisdictions may require additional non-Zigbee services, in which case additional regional specifications, services, and certifications may be required. These are outside the scope of ZSDK and this document.

This document describes how to build smart energy applications that can be tested by an independent test house, and certified compliant to the current certification level required by the Zigbee Alliance.

Note: *The scheduling and payment features are not yet supported on STM32WB since that STM32WB does not support the following clusters :*

- *Calendar*
- *Device management*
- *Prepayment*
- *Events*

Figure 1. Home Area Network



3 Smart energy regulatory environment

In the UK, Ofcom regulates wireless transmissions. Globally, in the 2.4 GHz band, Zigbee uses O-QPSK modulation on 15 channels while sharing for instance this ISM band with WiFi, or the Bluetooth®. The sub-GHz band Annex D of the Zigbee PRO R22 spec defines a special GB-868 transmission mechanism, which complies with European Telecommunications Standards Institute ETSI requirements, but deviates slightly from the European convention for this band, hence the name “GB-868” for this PHY. See R22 [11] Annex D for details.

Additionally, the department of business energy and industrial strategy (BEIS) regulates the utility companies, a national back-haul network provided by DCC, and the devices that utility companies use in smart energy deployments.

The baseline requirements are specified in smart metering equipment technical specifications: Second version (SMETS-II), and devices must implement the necessary device-specific features to comply with the requirements detailed in a specific version of this document. Zigbee requirements are only a subsection of SMETS-II, for instance DLMS/COSEM messaging. BEIS also requires compliance with the Great Britain Companion Specification (GBCS). There is an additional third document which only applies to Comms Hubs, The Comms Hub Technical Specification (CHTS). Devices developed for the UK market must comply with SMETS-II, GBCS, and CHTS for Comms Hubs. It should be noted most requirements imposed by these three specifications are unrelated to the Zigbee interface.

An important impact of GBCS on the Zigbee application concerns remote party messages. Remote party messages are end-to-end encrypted messages (from the back-haul head end system to the recipient device). They are transferred over the back-haul network and then over the Zigbee tunnel cluster to the recipient device. Remote party messages may be DLMS COSEM, ASN.1 or Zigbee ZCL (referred to as GBZ) messages. This means that a device may receive a given message as a regular Zigbee ZCL message or as a GBZ message via the tunnel cluster. DLMS COSEM, ASN.1 and the managing of GBZ messages are all outside the scope of the ZSDK Zigbee interface (however once the GBZ messages are decrypted they are handled by the ZSDK ZCL clusters in the same manner as a message received directly using the standard Zigbee mechanisms.

Products deployed on the UK must be tested by a Zigbee Authorized Test House and certified by the Zigbee Alliance. Certified devices must be utilizing a R22 Zigbee Compliant Platform. This includes Zigbee IEEE 802.15.4 PHY MAC certification covering the RF transceiver and antenna as well as R22 Stack. Following R22 Zigbee Compliant Platform Certification the device must also go through ZSE 1.4 Certification using ZSE Golden Units, also at a Zigbee Authorized Test House. ZSE 1.4 Certification is performed ECC (Elliptic Curve Cryptography) Test Certificates provided by Certicom. Once Certification is achieved, Production ECC certificates can be purchased from Certicom. Each device deployed to the field must contain a production certificate. In addition to Zigbee Compliant Platform and Zigbee SE 1.4 Certification, products deployed in the UK must undergo a Commercial Product Assurance (CPA) assessment as specified by BSI (British Standards Institute). Part of CPA is a MISRA (Motor Industry Software Reliability Association) report of which includes the application. Prior to deployment products may also have to go through interoperability testing in conjunction with DCC and or the utility company.

4 2.4 GHz and sub-GHz operation

Zigbee is built on IEEE 802.15.4-2015 [15] PHY/MAC layers and uses O-QPSK PHY ([15] Chapter 12) in the 2.4 GHz ISM band and in this band is the same as other Zigbee applications. Smart energy does place some specific requirements on Zigbee, such as requiring security and providing a mechanism for security key generation through CBKE, but on the whole smart energy operation in the 2.4 GHz band is similar to other Zigbee applications. However, smart energy is sometimes deployed where the RF characteristics of the 2.4 GHz ISM band are not ideal. The 2.4 GHz ISM band is crowded with other protocols such as WiFi, Bluetooth®, DECT, etc and these can interfere with ZigBee smart energy. 2.4 GHz signals also have a short propagation range and require line-of-sight because the signal is readily absorbed by objects in the signal path. In these less than ideal environments the Sub-GHz bands have significantly better performance so smart energy applications also permits Sub-GHz operation using the SUN FSK PHY ([15] Chapter 20). Sub-GHz operation in Europe is regulated by ETSI [22] EN 300-220 (note: ZSE 1.4 was developed when the UK was part of the EU) and the Sub-GHz operation was developed to meet ETSI Specs.

Zigbee PRO Core Specification [11] R22 Annex D defines the GB-868 PHY and facilities to maintain compliance with the ETSI requirements including: Duty Cycle Monitoring, Adaptive Power Control, and Listen Before Talk channel access. Note that R22 Annex D refers to the mode of operation as "European Sub-GHz", this is somewhat misleading as it is really designed for operation in the UK. As a result, it is commonly referred to as GB-868. GB-868 uses a starting frequency of 863.25 MHz (starting in channel page 28) whereas EU Sub-GHz bands start at 863.1 MHz (channel page 28). GB-868 also limits the available channels in pages 29 and 30.

GB-868 implements "polite" channel access mechanisms, specifically LBT (Listen Before Talk) and AFA (Adaptive Frequency Control). Because LBT+AFA is used the permissible duty cycle becomes 100s every hour (or effectively about 2.7% whereas it would be 0.1% without LBT+AFA), see R22 [11].

These polite channel access mechanisms as well as adaptive power control do not apply to 2.4 GHz operation.

4.1 Duty cycle monitoring

To ensure that a sub-GHz limits its transmission duty cycle to less than the regulatory limit, duty cycle monitoring is implemented. The duty cycle monitoring is performed through a combination of MAC and application level features. The MAC monitors its transmissions using a set of buckets that span a 1-hour interval. Transmissions during the bucket interval accumulate in the current bucket until the end of the bucket interval at which point a new bucket is started and the oldest bucket discarded. The sum of all the buckets is the total transmission during the last hour and this is available as a PIB parameter. When the regulatory limit is reached the MAC suspends transmission until enough buckets have expired. Before the regulatory limit is reached, there are lesser thresholds were only certain transmissions are permitted and this is reflected in the duty cycle mode accessible through a PIB value denoting the mode as NORMAL, LIMITED, CRITICAL or SUSPENDED.

4.2 Listen before talk (LBT)

The 2.4 GHz O-QPSK PHY uses carrier sense multiple access as the channel access method. CSMA requires transmitters to avoid collisions by listening for a carrier and only transmitting if a carrier is not detected (and otherwise backing off for a random interval before trying again). CSMA channel availability is determined by looking for a carrier, for instance a signal using the same modulation on the desired frequency. With LBT (listen before talk), the would-be transmitter monitors the energy on the desired frequency. The distinction is subtle but important, LBT is more likely to detect a transmission from a source using a different modulation scheme: it is a more polite channel access mechanism. The GB-868 PHY uses LBT instead of CSMA to comply with the ETSI regulations.

4.3 Adaptive frequency agility (AFA)

The GBCS and SMETS-II specifications were developed when the UK was part of the EU and fell under CEPT and ESTI regulations. To achieve 2.7% duty cycle, adaptive frequency agility is required. Zigbee meets this requirement through the frequency agility feature, see [11] Annex E, sections 2.4.3.3.10, and F.2.2. To support frequency agility, a device must be capable of operating on multiple channels. The section 5.8.1 of Zigbee Smart Energy Standard Version 1.4 ([1]) specifies the preferred 2.4 GHz channels 11, 14, 15, 19, 20, 24 and 25 and D.14 specifies the Sub-GHz channels on pages 28, 29, 30, and 31 and using ZbStartupConfigGetProSeDefaults() populates the startup configuration with these SE default channels.

Prior to forming a network, a scan is performed to locate a channel with the least likelihood of interference. Based on these scan results a network is formed on a preferred channel (or a channel on each 2.4 GHz and Sub-GHz bands in the case of a dual band ESI). However, conditions change over time and after repeated interference on a channel, the network may have no choice but to move to a new channel to avoid interference.

This behavior is known as frequency agility or adaptive frequency agility and support that allows applications to implement it is a standard feature of ZSDK.

5 Trust center swap out (TSCO)

Smart Energy deployments are often in the range of millions of individual Smart Energy HAN networks. Each individual network is expected to be long lived, with a potential lifetime of decades. With so many devices operating over such long a period of time, there might problems with a few individual devices on some networks, and some might be replaced. Replacing most devices is relatively straightforward, the replacement device is simply commissioned and added to the network in the same way as the original device was during the original provisioning.

Replacement of the ESI/Comms Hub (for instance the Trust Center) is not as straightforward. The Trust Center is the network coordinator (with the special short address 0x0000) and contains Install Codes and Link Keys (established via CBKE) with all of the devices on the network. Replacing the ESI is different from other devices on th network. As a result, the Trust Center Swap Out, or TSCO, procedure is required.

TCSO allows a Trust Center to be replaced without compromising the security of the network. The network key is never transmitted unencrypted, and neither the network key nor the individual link keys are ever used outside the respective devices.

When swapping TCs, the Extended PAN ID is retained and transferred to the new TC, allowing devices to locate the new TC. In addition, the existing link keys are hashed and used as a pre-configured link key on the new device. The original link key cannot be reconstructed from the hash.

6 Building smart energy applications using ZSDK cluster templates

Smart energy devices interact using ZCL clusters. Much of the work of implementing a smart energy device consists of completing the application specific functionality defined by those clusters. The ZSE [ref 1.4] and ZCL [ref 4] specifications define the interfaces and the required functionality. ZSDK provides template clusters, implementing the communication requirements and providing a template into which a smart energy application can be built.

A smart energy HAN consists of several nodes. In many cases a node consists of a single device type as defined in the smart energy specification. It is also possible that a node may support the functionality of more than one device type. Often the energy services interface (ESI) node is both an ESI device and metering device. Other nodes are generally a single device type such as the In-home display (IHD), programmable communicating thermostat (PCT), smart appliance, and prepayment terminal devices.

6.1 Smart Energy device types

Each physical Smart Energy device consist of one (or more) of the device types defined in the Smart Energy Spec, including:

- Energy Services Interface (ESI)
- Metering Device
- In-Home Display (IHD)
- Programmable Communicating Thermostat (PCT)
- Load Control Device
- Smart Appliance
- Prepayment terminal => not available on STM32WB
- Physical Device
- Remote Communications Device
- Linky ERL device => not available on STM32WB
- Range Extender

The ESI (Energy Services Interface) plays a special role in the network. Firstly it is normally the coordinator and Trust Center. Secondly, it is the device connected to the back-haul network.

In the UK Market the Zigbee ESI is part of a device known as a Comms Hub. Similarly other device types have UK specific names such as ESME, GSME and PPMID. These are defined in the Great Britain Companion Specification (GBCS) which is outside the scope of Zigbee and this Document.

The Zigbee Smart Energy spec defines a method for new devices to join a Smart Energy network in the form of an install code, often printed on the device itself. The install code must be conveyed over the back-haul network to the ESI, where it is used to create a Link Key on the Trust Center the device uses to join the network.

6.2 Overview of Smart Energy clusters

Smart Energy clusters provide base functionality as ZCL commands and attributes. Each specific implementation uses these features in different ways depending on the actual device, jurisdiction, and the utility company.

A Smart Energy Device is deployed to a specific market, and must be adapted to meet a specific set of requirements dictated in particular by:

- The business practices of the utility company
- The back-haul network provider’s infrastructure
- Regional and national governments

For example:

- One utility company may use a residential incline block pricing structure, where others may use time of use pricing.
- One regulator may require that customers must be issued emergency credit under certain circumstances.
- Sub-GHz channels are restricted regionally, and some regions have restrictions on power output and duty cycle. All of these requirements mean that a device must be targeted to a specific market.

Many of these requirements directly impact the design and business logic of the application. When designing an application these aspects must be taken into consideration. Some aspects are related to application use of the clusters; for example, some jurisdictions regulate how many and what type of calendars are used. Other aspects such as non-Zigbee legacy and proprietary messages tunneled over the tunneling cluster are completely outside the Zigbee specification.

ZSDK provides generic cluster templates that can be used to support the business logic in market specific applications for any device type. The following sections describe these generic cluster templates; the attributes, functions, callbacks, etc. that are required. The ZSDK cluster templates are developed to be certifiable by the ZigBee Alliance with the Zigbee Smart Energy Specification. Application development consists of implementing an often rich set of specific business logic required for a specific device in a specific Smart Energy market.

7 SE mandatory and optional clusters

The Smart Energy Spec [1] defines a set of mandatory and optional clusters to be supported depending on device type. Link Key (APS) security is required for most ZCL clusters with the exceptions as noted:

Table 2. Clusters used on a typical SE application

Cluster	Link Key Security Required
Basic	No
Key Establishment	No
Identify	No
Alarms	No
Power Configuration	No
Time	Yes
Commissioning	Yes
Keep-Alive	Yes
Price	Yes
Demand Response and Load Control	Yes
Metering	Yes
Messaging	Yes
Smart Energy Tunneling (Complex Metering)	Yes

A link key with the ESI is established automatically via CBKE when a device joins a Smart Energy network. When two non-ESI nodes, for example an IHD and meter, need to communicate the Link Key using the Partner Link Key mechanism defined in ZSE 1.4.

8 General clusters which do not require link key security

8.1 Basic cluster

The basic cluster is unique in that it is (normally) allocated automatically when the endpoint is created using ZclAddEndpoint(), and not allocated by the application. However, it is the applications responsibility to set attributes appropriately. Special helper functions are provided to assist in this process. Once all endpoints are allocated, the attributes of the Basic should be updated using ZbZclBasicWriteDirect(), specifying an endpoint ZB_ENDPOINT_BCAST. This updates the Basic cluster attributes on all endpoints.

The following attributes must be set in this way:

- ZCL_BASIC_ATTR_APP_VERSION
- ZCL_BASIC_ATTR_STACK_VERSION
- ZCL_BASIC_ATTR_HARDWARE_VERSION
- ZCL_BASIC_ATTR_MFR_NAME
- ZCL_BASIC_ATTR_MODEL_NAME
- ZCL_BASIC_ATTR_DATE_CODE
- ZCL_BASIC_ATTR_POWER_SOURCE
- ZCL_BASIC_ATTR_SW_BUILD_ID

Refer to the documentation on the Basic cluster and ZSE spec for the correct values to which these attributes should be set.

8.2 Certificate based key establishment (CBKE) cluster

The CBKE cluster is allocated automatically at startup when either suite 1, suite 2 or both suites are enabled, and certificates are defined in the ZbStartupCbkeT fields of ZbStartupT. See the Section 12 Device startup on a smart energy network and the ZSE 1.4 Specification for more information.

8.3 Identify cluster

The Identify cluster is an optional cluster for Smart Energy devices. However, making this cluster available is recommended to assist installers in verifying individual units. Other specifications such as BDB impose additional functionality on the Identify cluster, such as Finding and Binding. Such functionality is not used in Smart Energy networks where the only purpose of the cluster is to validate that the correct physical unit is being addressed.

8.4 Alarms cluster

The Alarms cluster is required when alarms are supported on other clusters, such as Basic, Metering, and Prepayment. When the application implements alarm support on one of these clusters, it must also create an alarm server cluster on the same endpoint as the cluster which generates the alarm. When the cluster application needs to generate an alarm it uses the ZbZclClusterSendAlarm() helper to generate the alarm.

Please see the documentation of the individual clusters for definitions of the alarms and alarm codes, and the documentation of the Alarm cluster for additional information. The ZSDK APIs can be found in Application Note AN-029 and AN-052.

8.5 Power configuration

The power configuration cluster is optional. It consists of a number of attributes clients may read to determine the characteristics of a device’s power supply, including main power or battery parameters.

See the cluster documentation for more details.

9 General clusters which do require link key security

9.1 Time cluster

Clocks in a Smart Energy network are synchronized using the time cluster, with the ESI acting as the server and clock master. Devices which rely on time can query the ESI and synchronize their clocks with the ESI. The devices must use APS link key security on all Time cluster messages and only accept or respond to link key secured requests.

9.2 Commissioning cluster

The commissioning cluster is listed as an optional cluster in the spec to allow for the possibility configuring devices wirelessly using a special commissioning tool. The ZSE Spec neither defines how this is done, nor precludes it. In practice the availability and use of the cluster would be dependent on jurisdiction, as many deployments do not make use of the commissioning cluster. When available, the commissioning cluster must only be accessible via APS Link Key secured messages.

9.3 Keep-Alive cluster

The Keep-Alive cluster is created automatically by the stack when CBKE is used. It is part of the mechanism by which Smart Energy devices detect loss of communication with the trust center. This loss of communication results in a sequence of retries, network re-join attempts, and ultimately an attempt to join a new trust center (TCSO). Applications should not declare instances of the Keep-Alive cluster. However, they do need to implement a device specific re-join sequence. See Section 12 Device startup on a smart energy network for more details.

10 Smart Energy clusters

This section contains information regarding the following Smart Energy clusters:
- Demand response and load control (DRLC)
- Messaging
- Metering
- Price
- Tunneling

10.1 Demand response load control cluster

A smart grid may not be able to meet the total demand during peak periods. For example, during a heat wave the demand for electrical power for heat pumps may exceed supply, resulting in rolling blackouts. The Demand response load control (DRLC) cluster provides a mechanism for utilities to shed load, better manage the grid, and even prevent failure under peak load conditions.

DRLC assumes an out of band mechanism from the head end over a separate back-haul network to the ESI. The application on the ESI responds by issuing DRLC events to devices on the Zigbee Smart Energy HAN. The term Event used in the ZSE Spec is somewhat misleading; a Load Control Event is a request from the ESI for a Smart Energy Device to change behavior for some duration, possibly at some point in the future.

An example Load control event may instruct a Programmable Controllable Thermostat (PCT) to adjust its setpoints (less heating or cooling). Although originally intended for thermostats, DRLC has been extended to a range of devices such as water heaters, swimming pools, appliances, commercial loads, and electric vehicles.

Load Control Events contain an Event Control field for randomizing the start time and/or the duration in order to prevent a scenario where potentially many thousands of devices across a Smart Grid simultaneously turn on or off.

A device does not always comply with a Load Control Event. Events are generally voluntary and devices may "opt-out" of participation. In some applications the occupant needs to "opt-in" to an event and the utility may offer an incentive, such as reduced rates, for participation.

The devices respond to Load Control Events by sending Report Event Status commands to the ESI. A single Load Control event often generates multiple Reports, each with a different status, such as "opt-in"/"opt-out", event started, event completed, event canceled, etc.

The cluster roles in the DRLC cluster may appear reversed from normal. The ESI is the DRLC server and the load-controlled device is the client. Clients support writable attributes to allow the ESI to assign groups, control randomization of start time and duration, as well as setting the device class.

10.1.1 DRLC server cluster on the ESI

On the ESI, the sever cluster is created using:

```
ZbZclDrlcServerAlloc()
```

Two callbacks are supported, one to receive asynchronous report status commands from the client:

```
void (*report_status)(struct ZbZclClusterT *clusterPtr, struct ZbZclAddrInfoT
*srcInfo, struct ZbZclDrlcStatusT *status, void *arg);
```

Status contains the Event Report Status command returned by the client.

The second server callback receives the response to a Get Scheduled Events request:

```
enum ZclStatusCodeT (*get_events)(struct ZbZclClusterT *clusterPtr, struct
ZbZclAddrInfoT *srcInfo, struct ZbZclDrlcGetEventsReqT *req, void *arg);
```

The ESI server can request Get Schedule Events using ZbZclDrlcServerCommandEventReq(). If no events are found on the client a status of ZCL_STATUS_NOT_FOUND is returned in the callback.

The server can also cancel a single event using ZbZclDrlcServerCommandEventReq() or all events using `ZbZclDrlcServerCommandEventReq().`

DRLC client cluster on the Controlled Device

On the controlled load device, the client cluster is created using:

```
ZbZclDrlcClientAlloc()
```

Because they are mandatory, all client attributes are created automatically and set to default values according to the Specification.

The DRLC client cluster manages the events received from the ESI internally, using timers to signal the application to start and stop events as needed. For this reason the client cluster automatically generates the Report Event Status callbacks with event code Command Received. See ZSE 1.4 [1], Figure D-8 and D-9.

The application must not attempt to also send these reports.

The client cluster interacts with the application via two callbacks provided to the cluster when it is instantiated via the alloc function:

```
bool (*start)(void *arg, struct ZbZclDrlcEventT *event)
```

```
void (*stop)(void *arg, struct ZbZclDrlcEventT *event)
```

The start callback should return true when the application wants the stop callback to be invoked at the end of the event. Typically when an error occurs in the start callback it returns false indicating to the client cluster that it does not want a stop callback at the end of the event.

The client application may decide to asynchronously send Reports to the ESI using the ZbZclDrlcClientCommandReportStatusReq() function. This is typically used for Opt-In and Opt-Out Event status reports. Because the DRLC client cluster manages the events, it also issues event cancellation status reports.

If an event is canceled between the start and stop callbacks the stop callback is invoked with the cancellation event allowing the application to take appropriate action.

In exceptional circumstances the DRLC client can lose the active events. This could happen for instance in an unexpected power cycle and restart from persistence of the load control device. In this case during restart the client should request that events be re-issued using:

```
ZbZclDrlcClientCommandGetEventsReq()
```

This results in the ESI reissuing the events it has in place for this load control device. This re-establishes the internal table and result in the start callback being called for active load control events. If the load control device is offline when the the stop callback should be called it cannot be called as a result of issuing ZbZclDrlcClientCommandGetEventsReq(). For this reason, the applications must assume the initial power-up state, which is the same as after completion of the stop callback. In this way the ESI and load control device remains synchronized, even in the rare event of temporary loss of communication due to a restart.

10.2 Messaging cluster

The messaging cluster provides a mechanism for an ESI to display simple textual messages on the display of a Smart Energy device, typically an IHD (In-Home Display), PCT (Programmable Communicating Thermostat), Smart Appliance or Prepayment Terminal. The device must has a display capable of displaying a short textual message.

Messages are sent from the ESI server to the device client (note that in some senses this is the opposite of the conventional client/server roles). Messages my require a confirmation that the user has received the message ("okay") and possibly a simple "yes/no" response.

On the ESI the server cluster is instantiated using ZbZclMsgServerAlloc() and the application provides callback functions to receive responses from the client. The ESI sends a message to the client using ZbZclMsgServerDisplayMessageReq() or ZbZclMsgServerDisplayProtectedMsgReq() when the message needs to be password protected. The display message request includes the message text, start time and duration in minutes. A message control field specifies the importance, whether receipt confirmation is required and whether a yes/no response is required (enhanced confirmation). The specification message control includes support for InterPAN transmission. This is included for legacy applications. InterPAN messaging is insecure and its use has been depreciated.

The client application creates the client cluster using ZbZclMsgClientAlloc(). On receipt of the display_message callback if a receipt confirmation or enhanced confirmation is required it calls ZbZclMsgClientConfReq() to send the confirmarion message back to the ESI.

The ESI may cancel a specific message using ZbZclMsgServerCancelMessageReq() or all active messages with ZbZclMsgServerCancelAllReq().

In the event of temporary loss of communication of the display device with the ESI, it should synchronize with the ESI by sending a ZbZclMsgClientGetLastReq() request it to re-send any Display Messages that had been previously sent. It is also possible that the client is still displaying a message that has been cancelled by the ESI. If still displaying a message it can use ZbZclMsgClientGetMsgCancelReq() to check wether the message should be cleared.

ZbZclMsgClientGetLastReq() and ZbZclMsgClientGetMsgCancelReq()

10.3 Keep-Alive

See Section 9.3 Keep-Alive cluster.

10.4 Metering cluster

The metering cluster is arguably the central cluster in Smart Energy applications. An electric, gas or water meter supports a server instance of the meter cluster, exposing a potentially diverse range of attributes to other Smart Energy devices. The primary Smart Energy client is the ESI, which relays metering information over the back-haul to the head-end system. In-Home Displays (IHD) and Programmable Controllable Thermostats (PCT) are also typical metering cluster clients. In many deployments the ESI and Meter are physically the same device, even though they are logically distinct in terms of their operation.

Some meters (typically gas or water meters) are battery powered and sleepy, and therefore not always available. This poses a problem for clients that require on-demand access to metering data. In these situations a mirroring facility is implemented, where the sleepy meter sends its meter data to an instance of the meter server cluster on the ESI, which mirrors the data, thereby making it always available to devices on the network.

The attributes of the metering server are divided into the following attribute sets:

- Reading Information Set
- TOU Information Set
- Meter Status
- Formatting
- Historical Consumption
- Load Profile Configuration
- Supply Limit
- Block Information (Delivered)
- Alarms
- Block Information (Received)
- Meter Billing Attribute Set
- Supply Control Attribute Set
- Alternative Historical Consumption

Attributes are intended to support a wide array of applications, and there are definitions for a large number of attributes to account for a diverse range of possible deployment scenarios. However, there are only a few mandatory attributes, and implementation of the remaining attributes is determined by the requirements of the specific deployment. Even though these attributes are optional in the Zigbee Smart Energy specification, their inclusion may be mandated by external requirement such as regional specifications. Definitions of many of the optional attributes are disabled in the ZSDK template and can be included as needed by the application.

10.4.1 Metering cluster attribute formatting

The mandatory attribute CurrentSummationDelivered is main meter reading value. Also mandatory are the MeteringDeviceType (such as Electric, Gas, Water and Thermal), UnitofMeasure (kWh, m3, BTU, etc.), and SummationFormatting attributes. CurrentSummationDelivered comes directly from the sensor, to obtain the actual displayed value the SummationFormatting attribute is used to format the value with the number of digits to the right and left of the decimal point. There are also two optional attributes Multiplier and Divisor, which if present and nonzero, are used to scale the meter reading value. The server provides the following attributes:

- CurrentSummationDelivered
- SummationFormatting
- Multiplier, Divisor
- MeteringDeviceType
- UnitsofMeasure

And the client combines these to correctly interpret and display the value. See [ZSE 1.4], Table D-24 for formatting examples.

In general, meters measure the quantity delivered. In some cases the meter may "run backward"; as in the case of solar photovoltaics generating electricity during the day and feeding it back into the grid at night. In such cases there are also "received" attributes available to record the amount energy delivered back to the grid.

Utilities seldom charge at flat rate. The complexities result in the need for a separate price cluster. It also impacts the attributes of the meter cluster. Two common schemes are Residential Incline Block (RIB) and Time Of Use (TOU). With RIB blocks of usage within a billing period are assigned. Usage up to the first block (for instance a specific number of kWh) are assigned the lowest pricing tier. If and when the blocks are exceeded usage in that block is billed at successively greater pricing tier. The block associated attributes including the CurrentBlockPeriodConsumptionDelivered, CurrentBlock, CurrentBlockReceived, etc. are all used when RIB pricing is used and not supported otherwise. When Block pricing and combined Tier-Block pricing is used, each unit of consumption is then added to one specific attribute in the Block Information Attribute Set Delivered or Received.

When TOU pricing is in place, the consumption is metered depending on the time of day each assigned a Tier. Each unit of consumption is then added to a tier specific attribute in the TOU Information Attribute set.

There are many more potential attributes organized into attribute sets including meter status, historical consumption, supply limits, meter billing, supply control and alternate historical consumption.

These optional attributes are only enabled and used as dictated by the requirements and business logic of the head end system. A specific meter contains an application specific implementation with a subset.

10.4.2 Metering cluster alarms

The metering cluster supports a wide range of potential alarms. The alarms available depend on the meter type (electric, gas, water, thermal). The Alarms Attribute set contains a set of alarm masks that allow an alarm client to selectively enable or disable generation of specific alarms. See [Ref ZSE 1.4] section D.3.2.2.9 for the definition of the alarm codes and alarm mask attributes.

When the meter cluster server application detects an alarm condition it posts the alarm using the helper function ZbZclClusterSendAlarm() from the meter server cluster. This results in generation of the alarm from the instance of the alarm server cluster on the same endpoint as the meter cluster server. See the alarms section of the [Ref ZSDK ZCL API] for more details.

10.4.3 Metering cluster and Fast Polling

It is typical for meter attributes to be updated every 30 seconds. In some cases, such as when a user actively watching an IHD screen, it is desirable to increase the update frequency. Zigbee provides the Fast Poll mechanism to enable this kind of temporary increase. Meter applications advertise the normal frequency in the DefaultUpdatePeriod attribute and the quickest supported fast poll as the FastPollUpdatePeriod attribute value.

The client requests fast polling by issuing a RequestFastPolling command to the server.

Note that the meter cluster fast polling mechanism is unrelated to the poll control cluster.

10.4.4 Metering cluster profiles

Cumulative usage on an hourly or daily basis is not fine grained enough to understand consumption patterns. A client could attempt to construct this information by performing regular reads, but this approach suffers issues due to time synchronization between client and server, and dealing with the possibility of missed reads. In order to resolve this issue, the metering cluster introduces the concept of profiles.

With profiles, the meter automatically accumulates the Consumption Delivered, Consumption Received, Reactive Consumption Delivered, and/or Reactive Consumption Received in a fixed number of buckets, up to the value of the MaxNumberOfPeriodsDelivered attribute. Each bucket covers a covering a fixed time interval as given by the ProfileIntervalPeriod attribute.

Meter clients can request this data using ZbZclMeterClientCommandGetProfileReq().

On the server when one of these commands is received, the application provided get_profile callback is invoked. The application then gathers the data it was accumulating in the background, and calls ZbZclMeterServerSendGetProfileRsp() to return the Profile data to the client.

On the client, the callback provided in the call to ZbZclMeterClientCommandGetProfileReq() is invoked with the Get Profile Response.

10.4.5 Metering cluster mirroring

A mirror is a duplicate meter cluster server instance located on a proxy device. It is used when the actual meter is on a sleepy node and not generally accessible. The mirror, which typically resides on the ESI, is always available to provide the metering data. A mirror can be distinguished from a physical meter by the Device Type attribute special "mirrored" device types are used and differentiate a physical meter from it’s mirror.

The meter cluster is mirrored using a one-way mirror. The mirror mechanism is defined in [ref ZSE] section D.3.4.4 Mirroring.

An ESI with the ability to act as a mirror provides a mirror discovery endpoint. This endpoint has, possibly in addition to other clusters, an instance of the Basic Cluster with the PhysicalEnvironment attribute set to 1 and a (potentially partial) instance of the Metering Server cluster. A sleepy meter that requires a mirror discovers the ESI, determines that it has mirroring capacity through the PhsicalEnvironment attribute and sends a RequestMirror command to the Metering Server cluster on the discovery endpoint. The ESI must then create a new mirror endpoint using ZbZclAddEndpointNoBasic() because the instance of the basic cluster on this endpoint is a mirror of Basic cluster on the mirroring device (not the ESI's Basic Cluster). The ESI adds a new Basic Server and Metering Server clusters to the new mirror endpoint and responds to the Request Mirror command with the endpoint ID of this new endpoint.

The application on the mirroring device then pushes the contents of its Basic Server and Meter Server cluster to the mirror using Attribute Reports. The sleepy meter is periodically wake, when it does meter server attributes that have changed are pushed to the mirror using Attribute Reports.

10.5 Price cluster

10.5.1 ESI pricing server

In a Smart Energy HAN the ESI is the server for providing pricing information to the HAN clients. devices. This cluster is highly configurable. Only the GetCurrentPrice and PriceAcknowledgement commands are mandatory, all other commands and attributes are optional. Only a fraction of the optional commands and attributes are implemented in an actual device, as needed to suit the specific regulatory and market requirements where it is deployed. The optional commands and attributes implemented are also to an extent driven by the needs of the application running on the device.

The ESI instantiates a Price Server instance by calling ZbZclPriceServerAlloc() and providing callback functions for the mandatory GetCurrentPrice and PriceAcknowledgement messages. There is also support for several of the more common optional commands and commands that are optional for Zigbee but mandatory in certain jurisdictions such as the GB market. If a callback is set to NULL, it is handled as an unsupported command. The special "optional" callback is provided for the application to add support for the less common commands. If needed the application must implement custom handlers for these commands.

Because all attributes are optional, ZbZclPriceServerAlloc() does not allocate any attributes. The application must allocate any optional clusters required. Attributes are divided into a number of attribute sets by the function of the attribute. The sets are also organized into two banks. The first bank is primarily for pricing concerning delivered consumption, the second bank duplicates the consumption attributes however is instead for the pricing of received energy. The received sets are only used when needed. Each set and the individual attributes are optional and depend on market requirements.

When used the price tier and block threshold attributes often occur in large blocks. In order to save space helper macros are provided to the application and ensure the correct resulting attribute id.

```
ZCL_PRICE_SVR_ATTR_TIERN_LABEL(1)
ZCL_PRICE_SVR_ATTR_TIERN_LABEL(2)
...
```

Pricing information is also distributed using a publish mechanism. The devices need to stay up to date with pricing data bind to the ESI pricing server cluster and receive publish commands such as PublishPrice. When prices change the ESI calls a publish command such as ZbZclPriceServerSendPublishPrice() publish the change to bound clients.

Price client device

Devices requiring pricing information instantiate a instance of the price client cluster using ZbZclPriceClientAlloc() provide a callback for publish price command. The remaining publish commands are optional and the application must implement its own handler using the generic optional callback.

Clients can send a GetCurrentPrice request to the server using ZbZclPriceClientCommandGetCurrentPriceReq(). There is also support for the most common optional commands including:

- ZbZclPriceClientCommandGetScheduledPricesReq
- ZbZclPriceClientCommandPriceAckReq
- ZbZclPriceClientCommandGetTariffInfoReq

- ZbZclPriceClientCommandGetPriceMatrixReq
- ZbZclPriceClientCommandGetBlockThresholdsReq

10.6 Tunneling cluster

The Tunneling cluster is also known as the Smart Energy tunneling or Complex Metering cluster. Although both a client and server role are defined, the data transfer mechanism of the tunnel is asynchronous; meaning either side performs a TransferData whenever it has data to send. As long as both sides agree on the type of data exchanged, the actual data is arbitrary.

The specification defines a set of ProtocolIDs including:

- DLMS/COSEM
- IEC
- 61107
- ANSI C12

The specification also allows for manufacturer defined protocols.

The server application creates an instance of the tunnel cluster using ZbZclTunnelServerAlloc(), and adds callbacks for supported protocols using ZbZclTunnelServerAddProto() for each supported protocol. Similarly, the client application ZbZclTunnelClientAlloc() creates an instance of the cluster and adds protocol support with ZbZclTunnelClientAddProto(). In both cases adding a protocol includes adding a set of callback functions to handle:

- Requests (for new tunnel sessions)
- Input (when data is received)
- Close (when the opposite side closes the tunnel)
- Error (when the opposite side signals an error)

The tunnel cluster (client and server) manages the connection through the ZbZclTunnelStateT pointer. The application does not and should not access its contents. The opaque state pointer is provided to the application in the callback from the ZbZclTunnelClientConnectReq() on the client or request callback provided to ZbZclTunnelServerAddProto() on the server. The application should save this state pointer and use it on all subsequent calls — it identifies the specific tunnel session.

Clients send data using ZbZclTunnelClientSendReq() and servers using ZbZclTunnelServerSendto(). The application provides a callback to handle ZCL responses, which may include a default response or one of the ZCL messages defined for the Tunnel cluster.

The client application can close the tunnel using ZbZclTunnelClientCloseReq(). The function ZbZclTunnelClientCloseQuietReq() is requires for ZSE certification tests but should not be used in a practical application as it does not send the required close message.

The server application can obtain the state pointer from the tunnel ID using ZbZclTunnelServerStateFindById() and use this on subsequent ZbZclTunnelServerSendto() requests. The servers can also send data to a specific Extended Address using ZbZclTunnelServerSendAllMatch().

It is important to note that the tunnel cluster simply provides a mechanism to exchange data back and forth between clients and servers. It is up to the application to implement for instance the details of the protocol DLMS/COSEM, IEC 61107, in the data.

A server arbitrarily closes a tunnel after a timeout period of inactivity. This timeout period is controlled by the ZCL_TUNNEL_ATTR_TIMEOUT attribute, which defaults to 3600 seconds or 1 hour. The server application can reset the local attribute using ZbZclAttrIntegerWrite() and the client can read the remote server attribute using ZbZclReadReq().

11 Partner Link Key

The Partner Link Key mechanism is defined in ZSE 1.4 section 5.4.7.4. During the partner link key procedure, the TC authenticates both partners and grants permission for them to establish their own link key. On completion of the partner link key procedure the devices then establish their own link key directly using CBKE. Here is an outline of the procedure (see also ZSE 1.4 figure 5-6):

1. Devices which accept establishment of a Partner Link Key do so by accepting a bind request on their CBKE cluster. The initiating device sends ZbApsmeBindReq() to the potential partner requesting a binding of the CBKE cluster back to itself. Usually a Match Descriptor Request is required on the potential partner to determine the endpoint of the CBKE cluster.
2. If the partner accepts the binding (for instance the status field of the ZbApsmeBindConfT response is ZB_STATUS_SUCCESS) then the potential partner has signalled that it is willing to attempt establishment of a partner link key.
3. The initiator then sends a Request Link Key to the TC using ZbApsmeRequestKeyReq() using the extended address of the potential partner with a keyType of ZB_APS_REQKEY_KEYTYPE_APP_LINK. Then, the TC authenticates both the initiator and potential partner, specifically both EUI-64 must be known to the TC, and not in any blacklist or certificate revocation list.
4. a/b If the potential both partners pass these checks, the TC sends a Transport Key message containing a unique link key to both the initiator and its potential partner.

   Although the partners could in theory use this link key, they do not. Instead, they use receipt of the Transport Key from the TC as permission to establish a partner link key. The key contained in the Transport Key message is not secure: it is, in practice, known to the TC. So, the partners discard the key from the Transport Key message.
5. The initiator then initiates CBKE directly with the potential partner using ZbZclKeWithDevice(). This initiates CBKE between partners identically to the way a joining device initiates CBKE with the TC during the initial join.

12 Device startup on a smart energy network

Joining or forming a smart energy network is very similar to other Zigbee networks. The stack is first initialized with a call to `ZbInit()`.

```
ZbInit() returns the a pointer to the stack instance that is used throughout the rest of the
application.
struct ZigBeeT *zb;
zb = ZbInit(ext_addr, &table_sizes, &logging);
   if (zb == NULL) { /* failed to initialize */
}
```

The stack is then started using ZbStartup() by providing it with the required configuration located in ZbStartupT.

```
struct ZbStartupT config;
```

A Smart Energy specific configuration helper is provided for the configuration items required by Smart Energy.

```
ZbStartupConfigGetProSeDefaults(&config)
```

During joining the Trust Center (TC) link key is used to encrypt the Transport Key message containing the network key. The initial TC link key is derived from a 48, 64, 96 or 128 bit install code to which a 16 bit CRC has been appended. The CRC is used to check the install code has not been altered. An install code could, for example, be printed on the device and manually entered by the user. The CRC in this case helps detect a transcription error. R22 [11] Section 5.4.8.1.1 describes the procedure for deriving the link key from the install code.

The function ZbSecInstallCodeCheck() verifies the CRC, and if correct, converts it to a 128 bit link key a joining device can use as its TC Link Key. Similarly the TC can use ZbSecAddDeviceLinkKeyByInstallCode() to add the link key for a device prior to it attempting to join.

The security certificates used for CBKE are configured in the cbke field of the ZbStartupT structure. The cbke field is of type ZbStartupCbkeT, and must be configured with either suite 1, suite 2 or both security certificates when CBKE is used. See [1] for more information on Smart Energy security.

In the ZbStartupCbkeT structure, the application must specify the Suite Mask (whether suite 1, suite 2 or both are supported). Setting one of these automatically triggers the creation of the CBKE cluster (and endpoint if needed), and automatically initiates the CBKE with the TC after a successful join. Additionally in the ZbStartupT structure the application can change the location of the CBKE cluster from the default endpoint, 240, to an another.

The ZbStartupCbkeT structure also controls the creation of the the Keep Alive cluster. The Keep Alive cluster is created automatically on the CBKE endpoint when CBKE is being used. Joining devices should set tc_keepalive_server_enable to false, the TC sets it to true and sets the tc_keepalive_base and tc_keepalive_jitter.

After startup the client reads these attributes on the server (TC) and re-reads them periodically based on the values returned. If this read fails several times, as defined in the TSCO procedure, the application provided callback tsco_callback is called.

The application must implement this TCSO callback and comply with the Keep Alive Method defined in [1] section 5.4.2.2.3.4 and Keep Alive Cluster as defined in ZSE 1.4 [1] Annex A.3 Keep-Alive Cluster.

The application then needs to specify whether the application is joining or in the case of a coordinator/TC, forming, a network.

```
config.startupControl = ZbStartTypeJoin; /* or ZbStartTypeForm */
```

The application then initiates network access with:

```
ZbStartup(zb, &config, startup_callback, &app_config);
```

13 Back-haul network certification

Back-haul networks exist entirely outside the scope of the Zigbee interface.

While the use of a back-haul network is common, the nature of the network and the regulatory environment surrounding it depends entirely on jurisdiction.

In the UK where SMETS-II and the GBCS are mandated, Smart DCC has produced a test tool GFI (GIT For Industry [note this GIT is not related to the version control system] — GIT actually stands for GBCS Interface Tool). This tool is located at: https://www.smartdcc.co.uk/products-services/gfi/ .

Smart DCC does conduct testing on ESME, GSME, IHD, PPMID, CAD and HCALCS devices. DCC has a Test Lab for devices and test scenarios are run through. The extent to which the GFI tool and/or real devices in the lab are used is presently unknown. There is more information in the above link.

In addition to this formal testing, device makers must also submit a Commercial Product Assurance (CPA) Document, which is a declaration of conformity generated by the device maker and submitted as part of the approval process.

More information about the CPA is located at: https://www.ncsc.gov.uk/information/commercial-product-assurancecpa

In addition to any other considerations mandated by the CPA, it also requires documented MISRA compliance.

Revision history

Table 3. Document revision history

Date	Revision	Changes
17-May-2021	1	Initial release.

Contents

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