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CHICKADEE

Wearable Badge Tracker

Technical Reference Manual

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List of Acronyms

Accl .... Accelerometer
ADR..... .... Adaptive Data Rate
ADDR .. .. ADDRess
ADV..... .... ADVertisement
App .... Application
AS........ .... ASia
AU....... .... AUstralia
BD .... Bluetooth Device
BLE .... Bluetooth Low Energy
CRC .... Cyclic Redundancy Check
DevEUI .... Device Extended Unique ID
DL........ .... DownLink
DR .... Data Rate
EIRP .... Equivalent Isotropically Radiated Power
EU .... Europe
FB........ .... Function Button
FCntDown........ Frame Counter Down
FSK...... .... Frequency-Shift Keying
FW .... FirmWare
GFSK ... . Gaussian FSK
GNSS ... . Global Navigation Satellite System[1]
GPS .... Global Positioning System
GRB..... .... Geolocation Resolver Backend
GW...... .... GateWay
HW...... .... Hardware
ID .... IDentity/IDentifier
IN .... India
Inc .... Incorporated
IoT....... .... Internet of Things
IP......... .... Ingress Protection
ISM .... Industrial, Scientific, and Medical
JSON ... . JavaScript Object Notation
KR .... KoRea
LAP...... .... Lower Address Part
LED...... .... Light-Emitting Diode
LoRa.... .... Long Range
LoRaMAC......... LoRaWAN MAC
LoRaWAN........ LoRa Wide Area Network
LoS .... Line-of-Sight
LPGNSS............ Low Power GNSS[2]
LSb .... Least Significant bit
LSB .... Least Significant Byte
MAC.... .... Medium Access Control
Max .... Maximum
MCU.... .... MicroController Unit
MSb .... Most Significant bit
MSB .... Most Significant Byte
NAV .... NAVigation
NE .... North East
NLoS ... . Near LoS
NS .... Network Server
OTA..... .... Over-The-Air
OUI .... Organizationally Unique Identifier
PCBA... .... Printed Circuit Board Assembly
PDU .... Protocol Data Unit
POST... .... Power-On Self-Test
R .... Read
RF........ .... Radio Frequency
RFU..... .... Reserved for Future Use
RO....... .... Read-Only
RSSI..... .... Received Signal Strength Indicator
RTLS.... .... Real-Time Location System
RU....... .... RUssia
Rx........ .... Receiver / Receive
SNR..... .... Signal-to-Noise Ratio
SW .... SoftWare
T.......... .... Temperature
TRM.... .... Technical Reference Manual
Tx........ .... Transmitter / Transmit
UID...... .... Unique ID
UG....... .... User Guide
UL .... UpLink
v.......... .... version
W........ .... Write
Wi-Fi... .... Wireless-Fidelity
X.......... .... eXecutable

[1] GNSS will also be used in reference to the ublox MAX-M10S receiver built into CHICKADEE

[2] LPGNSS will also be used in reference to the LR1110 receiver built into CHICKADEE

1 Introduction

IMPORTANT: Not all features described in this manual may be applicable to sensors programmed with older FW versions. Refer to the Revision History table to verify which FW versions included the addition of new features. To check which version of FW your sensor has, send a query as described in §4.4.4.

This document contains the technical information about the supported functionality of the TEKTELIC *CHICKADEE Wearable Badge Tracker*, referred to as CHICKADEE or *sensor*. In particular, the LoRa IoT uplink and downlink payload structures and user-accessible configuration settings are described in detail. This document assumes an understanding of the NS and its command interfaces.

1.1 Overview

CHICKADEE is a low-power LoRaWAN IoT sensor powered by a Li-Po rechargeable battery and built into a compact IP67 polycarbonate casing. Its' primary purpose is location tracking both indoors and outdoors using a combination of location-tracking technologies:

- ***GNSS:*** Outdoor tracking using satellite geolocation. There are two GNSS receivers built into Chickadee:
    - Low-power GNSS (LPGNSS) using the Semtech LR1110 transceiver.
      Note: The acronym "LPGNSS" will refer to the LR1110 from this point on in this document.
    - High precision GNSS using the ublox MAX-M10S transceiver.
      Note: The acronym "GNSS" will refer to the MAX-M10S from this point on in this document.
- ***Wi-Fi Sniffing:*** Outdoor and/or indoor tracking using Wi-Fi access point geolocation.
- ***BLE Tracking:*** Indoor tracking using BLE beacon network localization.

CHICKADEE is meant to be a component in an end-to-end tracking solution as shown in Figure 1-1.[3]

[3] **NOTE**: Only raw scan data is present in the LoRaWAN payloads, not sensor location information. In order to track and visualize a CHICKADEE's location, an application server must be set up, integrated with the NS, and enabled to use the proper cloud location services. The information in this document is for the CHICKADEE sensor only; for information about setting up the rest of the end-to-end solution shown in Figure 1-1, refer to the TEKTELIC support portal Knowledge Base [6].

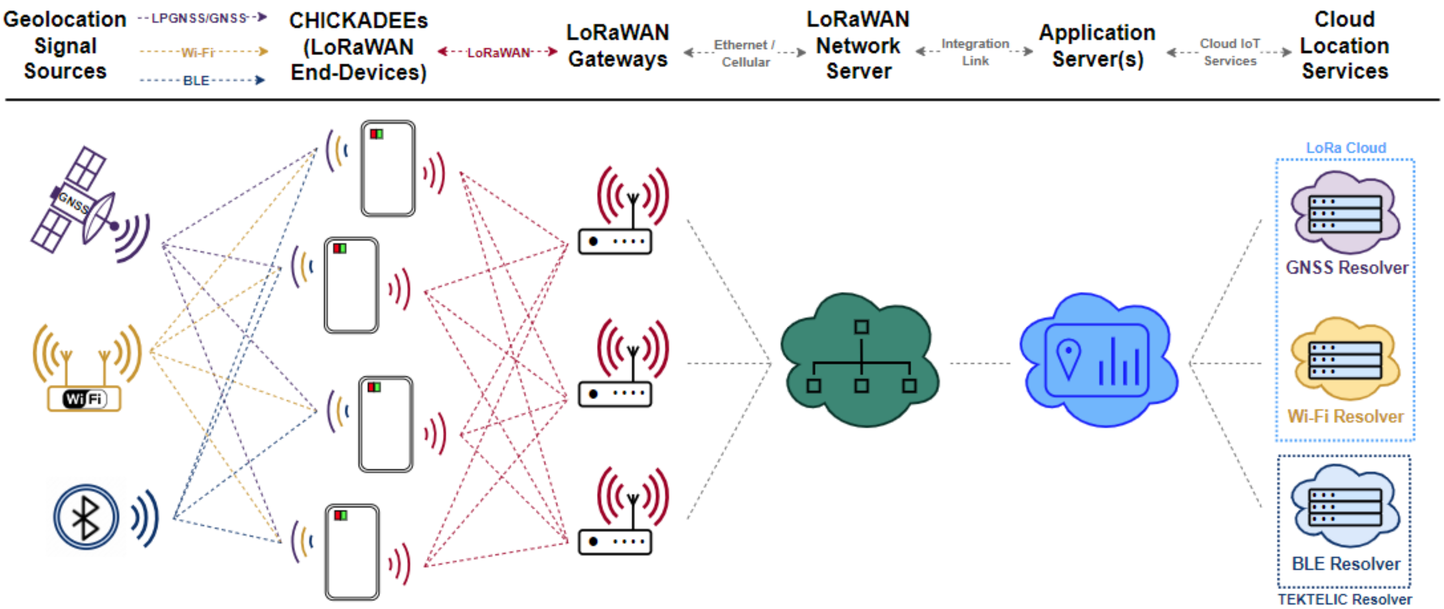

Figure 1-1: CHICKADEE Location Tracking End-to-End Architecture

The location information flows in this order:

1. CHICKADEE conducts LPGNSS, GNSS, Wi-Fi, and/or BLE scans to gather raw information from the available geolocation signal sources.
2. The raw scan results are conveyed via LoRa transmissions to 1 or more *LoRaWAN GateWays* (*GW*s).
3. The GWs forward the packets to the *LoRaWAN Network Server* (*NS*) either by ethernet or cellular backhaul.
4. The raw scan results are forwarded to the application layer via *integration link*.
5. The application determines which *Cloud IoT Location Resolver Service*(s) to use depending on what type of scan data is forwarded.
6. The respective location resolver service processes the raw scan data to calculate a position fix.
    a. LPGNSS scan data messages are designed to be processed by Semtech's *LoRa Cloud* service.
    b. BLE scan data messages are designed to be processed by TEKTELIC's *Geolocation Resolver Backend* (*GRB*) and is supported by TEKTELIC's LOCUS application.
    c. Wi-Fi scan data messages can be processed with 3rd party applications.
7. The resolved fixes are returned to the application where they can then be visualized on a virtual dashboard.

In addition to geolocation, CHICKADEE is a multipurpose device equipped with a variety of technology:

- **Core design**: The core design is based on an MCU, which runs the system SW and has a built-in BLE module. One transceiver handles the LoRa, LPGNSS, and Wi-Fi operations. Another transceiver handles the GNSS operations.
- **Accelerometer**: Detects device motion state so geolocation updates can be sent more frequently while in motion. Motion alarms and the raw acceleration vector can also be reported if knowledge of sensor orientation is enabled.
- **BLE tracker mode**: In this mode, the sensor is in BLE receive only to conduct geolocation tracking.
- **BLE beacon mode**: In this mode, the sensor broadcasts BLE advertisements which make it discoverable by other nearby trackers or BLE-capable devices.
- **MCU temperature sensing**: The temperature of the MCU can be reported, and additional reports can be sent if the conditions cross configurable thresholds.
- **Battery data**: The remaining capacity and lifetime can be reported. The battery lifetime has been estimated to be 6 months.

LoRaWAN is the LoRa wireless communications standard protocol. This technology provides a low-bandwidth, low-power, and long-range[4] means of transmitting small amounts of data. It has been developed with wireless sensing in mind, and to enable new means of gathering telemetry in numerous environments. CHICKADEE supports LoRa and (G)FSK modulations according to the **LoRaWAN L2 1.0.4 Specification** [1]. The 867 MHz - 928 MHz ISM bands (NA and EU) are utilized to meet different application requirements from the standards and proprietary protocols of the given region.

1.2 Summary of HW Information, Streams, and Default Behaviour

Table 1-1 presents the currently available sensor HW variants. The information streams supported by the SW have been shown in Table 1-2, and the default configuration for reporting data has been shown in Table 1-3.

Table 1-1: CHICKADEE HW Models

Product Code, Module-Level T-Code	Product Code, PCBA-Level T-Code	Model Name	Description	LoRaWAN Regions Supported[5]
T0008534	T0008492	CHICKADEE	GNSS-Wi-Fi-BLE Location Tracking Sensor	EU868
				US915

[4] Up to 2 km NLoS and more than 22 km LoS.

[5] Other regional variants available upon request.

Table 1-2: List of CHICKADEE Information Streams

Stream Direction	Data Type	Sent on LoRaWAN Port [decimal]
UL (Sensor to NS)	Reports containing sensor data: • **GNSS** location fix ("0x00 00 00") means "no fix found" after GNSS scan • Battery life data • Accelerometer vectors and alarms • MCU temperature • Geolocation cycle failed message	**10**
	Responses to read/write configuration and control commands	**100/101**
	LPGNSS scan results to be forwarded to LoRa Cloud	**192**
	Reports containing discovered BLE device data	**25**
	Wi-Fi scan results to be forwarded to LoRa Cloud	**197**
	LoRa Cloud requests	**199**
DL (NS to Sensor)	Putting sensor into DEEP SLEEP	**99**
	Configuration and control commands	**100**
	LoRa Cloud communications	**192/199**

Table 1-3: CHICKADEE Default Reporting Behavior

Report	Report Type	Default Periodicity
Battery data	Periodic	24 hours
	Event-based	When function button is pressed
Geolocation Update	Periodic	10 min when in motion (LPGNSS/GNSS) 1 hour when still (LPGNSS/GNSS)
Acceleration vector	Periodic	Disabled
Accelerometer motion alarm	Event-based	When motion is detected When sensor becomes still
MCU temperature	Periodic	1 hour
	Threshold-based	Disabled

1.3 Finite State Machine

The finite state machine (FSM) for the CHICKADEE system provides a comprehensive overview of the system's behavior, outlining the transitions between various operational states and the associated behaviors for each state and transition. In this model, the system is capable of existing in only one state at any given time, and state transitions are triggered by external inputs or events, such as a button press.

Figure 1-2 illustrates the state machine of CHICKADEE. Below is an in-depth explanation of each operational state:

1. **DEEP SLEEP:** In this state, CHICKADEE's MCU enters a deep sleep mode to minimize energy consumption. The device defaults to this state upon factory initialization. Applying power to the USB-C connector wakes the CHICKADEE into STARTUP. Sending a DL returns CHICKADEE to DEEP SLEEP (refer to §3.3.1).

2. **STARTUP:** The STARTUP state marks the initial boot-up phase of CHICKADEE, where the device undergoes essential procedures such as Power-On Self Tests (POSTs) and other initialization tasks. These preparations are conducted to ensure the system is ready to commence the process of joining the LoRa network. The CHICKADEE transitions into this state following a successful reset or wake-up from DEEP SLEEP mode.

3. **JOIN:** In the JOIN state, CHICKADEE endeavors to connect to a LoRa network. Initially, the two LEDs flash rapidly, signaling the initiation of this process, with this rapid flashing lasting for the first hour. Subsequently, the flashing rate slows down to conserve battery life. Throughout the entire joining process, the LEDs flash each time CHICKADEE sends a join request uplink, providing visual feedback of the ongoing network connection attempt.

4. **NORMAL:** Upon successfully completing the JOIN process, CHICKADEE transitions to the NORMAL state. In this state, the device regularly sends geolocation and transducer information. **LPGNSS** is the first scan type performed by default in the geolocation cycle (where more than one scan type may be performed).

5. **EMERGENCY:** Transitioning to the EMERGENCY state occurs when pressing and holding the Emergency Button (EB) for 2 s.

   Upon entering this state, the following actions occur:
   a. The buzzer emits a local acknowledgment sound and follows an emergency active buzz pattern to alert both the wearer and nearby individuals. This pattern will repeat until emergency mode is exited.
   b. The RED LED will flash rapidly and periodically, providing a visual indication of the emergency situation.
   c. Geolocation data (starting with **GNSS** by default) are reported at an increased rate to provide comprehensive information. This rate is every 4 minutes as defined by register 0x 24.
   d. If the unit is configured for additional geolocation scan types to occur aside from GNSS, they will continue to be performed while CHICKADEE is in the EMERGENCY state.

The transition back to the NORMAL state occurs when the EB is pressed a second time for 2 s. Additionally, if the device resets or restarts while in an active emergency state, the emergency button state remains active upon rejoining the network. This prevents the loss of an active emergency and ensures continued monitoring and response to critical situations.

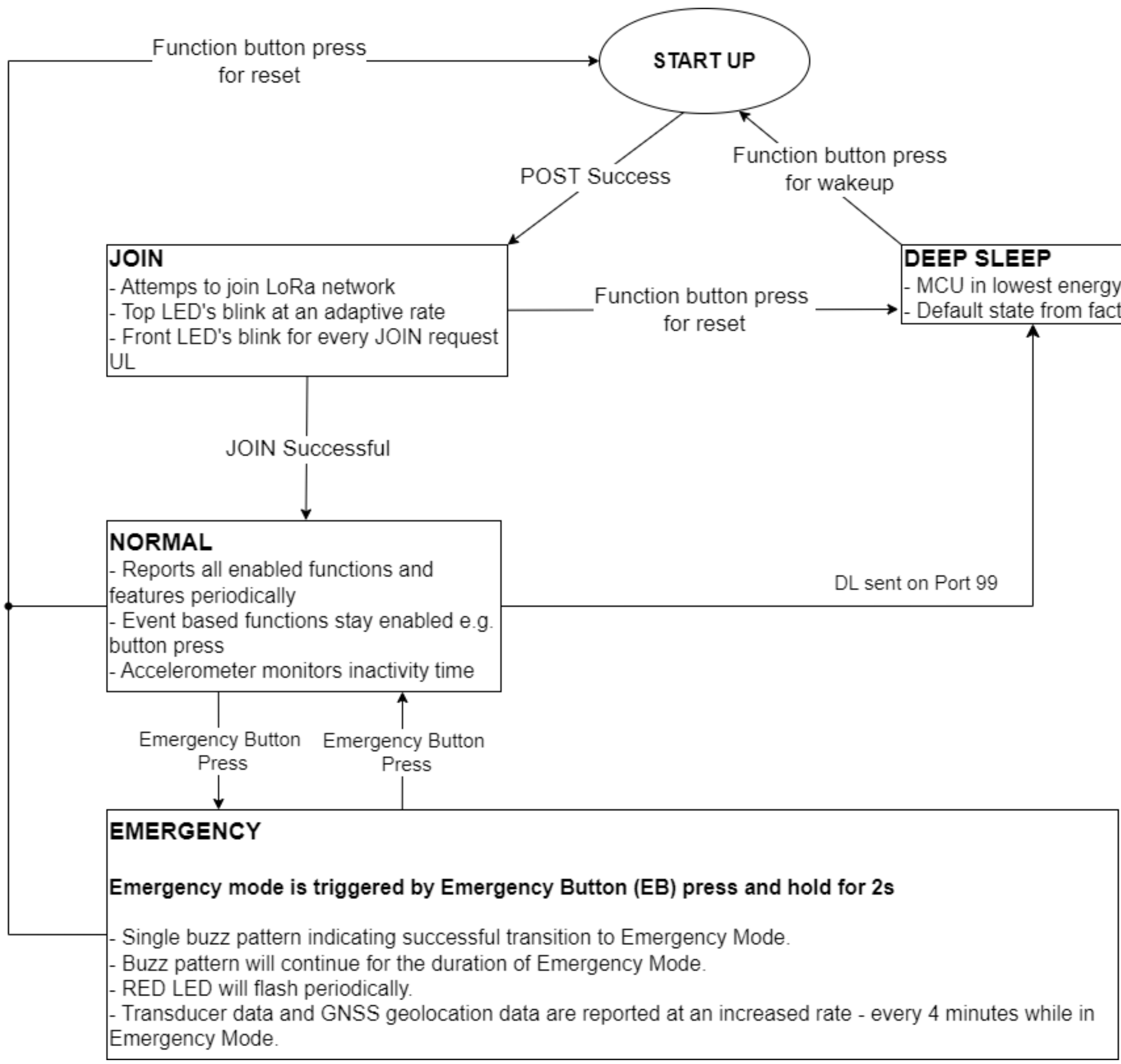

Figure 1-2: Finite State Machine

1.4 Scope

The following subsections provide a more detailed description of the functionality of each of the user interfaces and subsystems available on CHICKADEE. They are organized as follows:

- External User Interface Hardware (§2)
  - LED’s
  - Emergency Button
  - Function Button
  - Buzzer
  - USB-C connector

- General Configuration Settings and LoRaWAN Payload Formats (§3)
- Basic Operation (§4)
    - LoRaMAC Options
    - Periodic Report Scheduling
    - Battery Management
    - General Command and Control Operations
- Geolocation (§5)
    - Scan Cycle and Resolving LPGNSS, GNSS, Wi-Fi, and BLE Locations
- BLE Operation (§6)
    - Tracker Mode
    - Beacon Mode
- Accelerometer Operation (§7)
    - General Sampling Behaviour
    - Orientation Detection
    - Motion Detection Alarms
    - Accelerometer Assist for Geolocation
- MCU Temperature Sensing (§8)
    - Temperature Reporting
    - Threshold-Based Reporting
- System Diagnostics (§9)
    - Reset Diagnostics
    - Error Diagnostics

2 External User Interface Hardware

CHICKADEE enclosure is shown in Figure 2-1 and the locations of the external user interface hardware are identified. The LED behaviour is described in the following subsection.

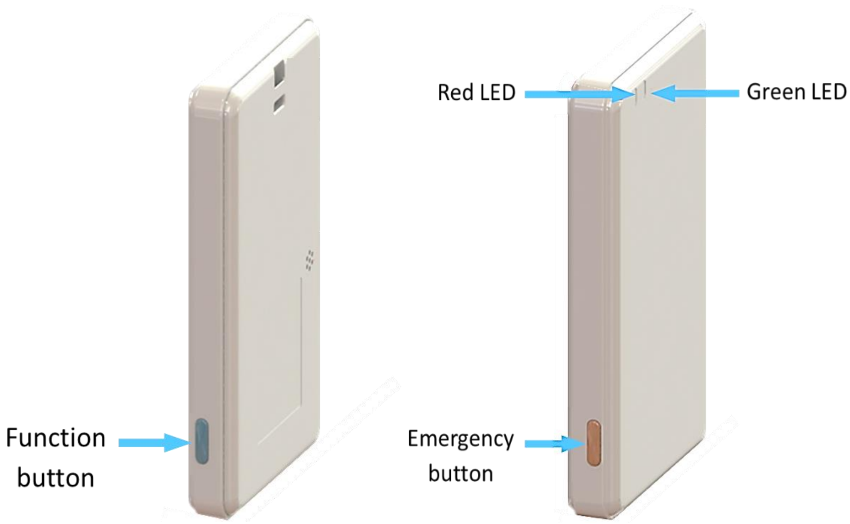

Figure 2-1: External User Interfaces on CHICKADEE Enclosure

2.1 LED Behaviour

The sensor is equipped with two on-board LEDs: **GREEN** and **RED**. They are visible through holes in the sensor enclosure at the locations shown in Figure 2-1. The LED behaviour is not user configurable.

The LEDs are normally off. Their blinking patterns reflect different actions and states of the sensor. At a high level, the main patterns are summarized in Table 2-1.

Table 2-1: Summary of LED Patterns

LED Pattern	Meaning
GREEN blinking rapidly and a single **RED** flash every time a JOIN REQUEST is sent (~40 s)	JOIN mode; attempting to join the network
Single **RED** flash	UL sent
Single **GREEN** flash	DL received
Pattern for EMERGENCY	Entering and exiting EMERGENCY state, by pressing and holding the **Emergency Button** for 2 s
Solid **RED**[6]	Battery charging
Solid **GREEN**	Battery charging complete. **GREEN** LED will stay on until USB-C charging cable is disconnected.

[6] **While the battery is charging, the RED and GREEN LED activity for LoRa UL and DL are suspended.**

2.2 Emergency Button

CHICKADEE is equipped with an Emergency Button (EB), which is used for the following purposes:

1. EB Active event: Pressing and holding the EB for at least 2 s sounds the buzzer[7] with the emergency active buzz pattern, flashes the LEDs, sends location information, and makes a system state transition to the EMERGENCY state (if already not in that state). The buzzer will repeat the pattern every 10 s while in the EMERGENCY state.
2. EB Inactive event: Pressing and holding the EB for at least 2 s while in the EMERGENCY state turns the buzzer off, stops the periodic LED flashes, sends location information, and makes a system state transition to the NORMAL state.

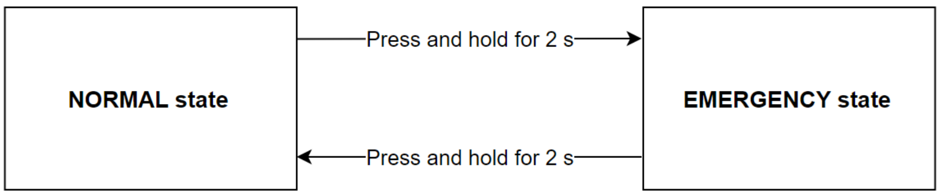

Figure 2-2: EB activation and deactivation block diagram

Geolocation cycles and scan order logic, as explained in §5.1.1, are configurable while CHICKADEE is in EMERGENCY STATE.

2.3 Function Button

CHICKADEE is equipped with a second button, the Function Button (FB), which is used for several purposes, depending on how the button is pressed, or pressed and held down.

1. **Activating the device**: When shipped from the factory, a CHICKADEE unit is in DEEP SLEEP mode to conserve the battery capacity. To wake it up and have it join the network, press the Function Button once quickly, then press and hold the button for 3 s. After this button pattern the unit will turn on and try to join the network server.
2. **Forcing an uplink**[8]: Press the button and hold for 1 s to send an uplink which contains the battery status. The RED LED will flash indicating that the uplink was sent.
3. **Resetting**: Press the button once quickly, then press and hold the button for 3 s.

[7] The buzz pattern for entering and exiting EMERGENCY state is non-configurable.

[8] As a Class-A LoRaWAN end-device, the sensor only opens LoRaWAN receive windows immediately following uplink transmissions [1]. It is therefore useful to be able to force the sensor to UL so that it can receive DL configuration commands from the NS ahead of its next scheduled periodic report.

2.4 Buzzer

The buzzer will beep certain ways based on the event as shown in Table 2-2 below:

Event	Tune or Sound
EB enter	Three long beeps
EB exit	Three medium beeps
EB Active event	Four short beeps

Table 2-2: Buzzer Tunes and Sounds

2.5 USB-C Connector

There is a single USB-C connector on the bottom of CHICKADEE. This connector is used to charge the battery inside the device. The USB-C connector is only used for charging and supports a voltage range of 5 V – 15 V. The USB-C connector cannot be used for data transfer to or from CHICKADEE.

3 General Configuration Settings and LoRaWAN Payload Formats

CHICKADEE communicates with the NS using LoRaWAN packets [1]. The communication behaviour as well as other device-level behaviour is configurable through SW settings. The following subsections describe the general configuration settings format, communication streams, and packet formats supported by CHICKADEE.

There is an online application called *KONA ATLAS* available as a comprehensive packet codec tool [2]. It supports encoding DL payloads and decoding UL payloads for CHICKADEE.

3.1 Configuration Settings Format

Configuration settings are saved in the flash storage *configuration registers*. Each register has an *address* that is assigned to a particular setting or action. These addresses are bound between 0x 00 and 0x 7F, inclusive. The bit indexing scheme for register addresses and values is as shown in Figure 3-1.

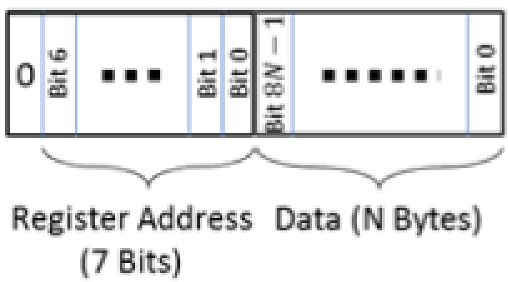

Figure 3-1: Bit Indexing Scheme for Configuration Registers

Possible register access permission options are read/write (R/W), read only (RO), or executable (X). Accessing each register involves *configuration and control commands*. The general formats are described in §3.3.2.

For a complete summary list of the specific definitions, sizes, and default values of all configuration registers, see Table A2-1Table in Appendix 2 .

3.2 UL Payload Formats

Uplinks (ULs) are LoRaWAN packets sent from the sensor to the NS. They are used for the following purposes in CHICKADEE[9]:

[9] Here “ULs” means “SW application-layer ULs” or “LR1110 middleware ULs;” there are other MAC-layer ULs that the sensor may send to perform LoRaMAC operations. LoRaMAC behaviour occurs according to the LoRaWAN specifications and is outside the scope of this document [1].

1. **Reports** containing real time sensor data.
2. **Responses** to configuration and control commands[10].
3. **LoRa Cloud communications** including GNSS and Wi-Fi scan results and GNSS information requests.

Each UL is sent on the appropriate upstream port. The UL streams supported by the SW are shown in Table 1-2.

3.2.1 Sensor Data Reports (LoRaWAN Port 10 ULs)

All sensor data reports that are sent on **LoRaWAN port 10** fall into one of the following reporting categories:

- **Periodic Reporting**: Scheduled reporting of sensor data at regular, configurable intervals. The reporting intervals are configured using the tick registers as described in §4.2.
- **Event-Based Reporting**: Various external events can trigger unscheduled sensor data reports on interrupt. These events include motion detection, stillness detection, and temperature threshold breaches. Each event elicits a different type of response from the sensor. Not all event-based reporting is enabled by default.
- **GNSS location reports: S**cheduled reporting of UTC time, position coordinates, and ground speed.

The **LoRaWAN port 10** UL report payload is encoded in a general frame format ~~shown~~ depicted in Figure 3-2. A big-endian format (MSb/MSB first) is always followed. This format is the same for periodic reports, event-based reports, and GNSS location reports. A single sensor data report payload can include multiple data frames from different sensing components and these frames can be arranged in any order.

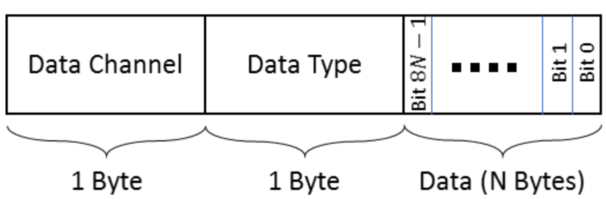

Figure 3-2: The UL Frame Format of a Sensor Data Report

For a complete summary list of specific **LoRaWAN port 10** UL frame formats, refer to Table A1-1.

The specific frame details are also included in the corresponding function-specific sections: §4.3.2 (battery data), §7.2.2 (accelerometer vector), §7.3.2 (accelerometer alarms), §5.1.2 (geolocation data), and §8.1.2 (temperature data).

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[10] See §3.3.2 for a description of configuration and control commands.

3.2.2 BLE Scan Reports (LoRaWAN Port 25 ULs)

Discovered BLE device data are sent in reports on **LoRaWAN port 25**. BLE reporting payload structures differ from the other sensor report formats described above. See §6.1.2 for a complete description of BLE reporting behaviour. See Figure A1-2 and Figure A1-3Figure in Appendix 1 for a depiction of the frame formats.

3.2.3 Responses to Commands (LoRaWAN Port 100 and 101 ULs)

The sensor sends ULs in response to any DLs received which contain configuration and control commands[11]. These UL responses include 2 types:

- **Read response (LoRaWAN port 100)**: returning the value of a configuration register in response to a query from a DL read command block.
- **Write/Error response (LoRaWAN port 101)**: Returning an acknowledgement after a successful reconfiguration of a register(s), or an error message informing of an unsuccessful command.

Received command blocks are processed one-at-a-time in order from MSB to LSB, with the following exception:

- General command-and-control operations are queued to be processed last, and in the following order. See §4.4.
    1. Save configuration settings to flash.
    2. Reset configuration settings to factory default.
    3. Reset sensor.

3.2.3.1 Read Response

A message UL is returned on **LoRaWAN port 100** containing the addresses and values of each of the registers under query (this can be in one or more consecutive UL packets depending on the maximum frame payload size allowed at the current data rate). The bit indexing scheme is the same as for configuration registers, which is shown in Figure 3-1.

If the sensor receives a read command trying to access a register that is designated as RFU, the address is included in the error response as described in §3.2.3.2.

3.2.3.2 Write/Error Response

A message UL is sent on **LoRaWAN port 101** with the frame format as shown in Figure 3-3.

[11] See §3.3.2 for a description of configuration and control commands.

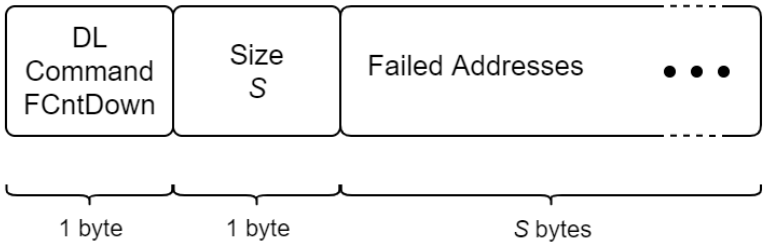


Figure 3-3: The LoRaWAN port 101 Write Response UL Frame Format

The contents of the frame include:

- *DL Command FCntDown*: the last byte of the LoRaWAN frame count down number of the DL payload which contained the write command [1].
- *Size*: the number of registers, *S*, that were not successfully written to, and therefore the size of the rest of the payload. *S* can range from 0 to 15
- *Failed Addresses*: the address(es) of the register(s) where the command(s) failed.

If all commands were successful, *S* = 0x 00 and no failed addresses are included. This includes if a redundant write command was issued (i.e., the value of that register did not change).

As soon as the sensor encounters an invalid command block[12] (read or write), the address of that command block is added to the port 101 response and no further command blocks are processed. If there were any command-and-control operations queued to be processed, their addresses are also added to the port 101 response, and they are not executed.

If anti-bricking is activated, register 0x 21 will be added to the port 101 response. If there were any command-and-control operations queued to be processed, their addresses are also added to the port 101 response, and they are not executed. See §4.2.1.1. for more details about anti-bricking.

The sensor will respond this way to all read and/or write commands, except for these 2 cases:

- If a reset command is present, the sensor will reset and not send any response UL. The sensor resetting is an indication that all commands were successful.
- If a command is encountered to switch between BLE modes, the sensor immediately stops processing other command blocks and switches modes as described in §6.3. No response UL is sent.

Note: Port 101 responses may be delayed because of port 100 responses taking precedence.

[12] An invalid command is one that either tries to access a register designated as RFU or write an invalid value to an accessible register.

3.2.3.3 Example UL Payloads

- **LoRaWAN port 100*:* 0x 20 00 00 00 3C 21 00 01**
  - Read response
  - Register 0x 20 (seconds per core tick)
    - Value read = 0x 00 00 00 3C = 60 s per core tick
  - Register 0x 21 (ticks per battery report)
    - Value read = 0x 00 01 = 1 tick per battery report
- **LoRaWAN port 101*:* 0x 0F 00**
  - Write response
  - 0x 0F → Response to write command in DL with FCntDown ending in 15
  - 0x 00 → Size = 0; no failed write commands
- **LoRaWAN port 101*:* 0x 03 04 15 16 17 18**
  - Write response
  - 0x 03 → Response to write command in DL with FCntDown ending in 3
  - 0x 04 → Size = 4; 4 failed write commands
  - 0x 15 16 17 18 → The write commands attempting to overwrite registers 0x 15, 0x 16, 0x 17, and 0x 18 all failed.

3.2.4 LoRa Cloud Communications (LoRaWAN Port 192, 197, and 199 ULs)

In the uplink direction, **LoRaWAN ports 192**, **197**, and **199** are used for LoRa Cloud positioning information (ports 192 and 197) and device management (port 199). These processes occur according to the specifications of LoRa Cloud [3]. The behaviour is not configurable and therefore outside the scope of this document.

LPGNSS and Wi-Fi scan results are sent in uplinks on **LoRaWAN ports 192** and **197**, respectively, where they can then be forwarded to the LoRa Cloud geolocation resolver.

LoRaWAN port 199 is used for positioning assistance, for such things as clock sync and almanac requests. Clock sync requests are sent in uplinks and begin with 0x **17 01**. Almanac requests are sent in uplinks and begin with 0x **18**.

Note: Once a CHICKADEE device has joined the NS, and has started almanac handshaking with uplinks and downlinks back and forth, it is important not to switch the device to a different account that uses a different token provided by Semtech. Doing so will result in no LPGNSS scan results being sent to LoRa Cloud on port 192. Should this happen, the downlink 0x 00 00 0A 6F BF 00 00 04 to port 199 will resolve the issue.

For more troubleshooting information, please see Appendix 4 .

3.3 DL Payload Formats and Configuration Settings

Downlinks (DLs) are LoRaWAN packets sent from the NS to the sensor. They are used for the following purposes in the CHICKADEE sensor[13]:

1. To read the current configuration settings of the sensor (**R**).
2. To change the current configuration settings of the sensor (**W**).
3. To cause the sensor to perform an operation, such as reset or enter DEEP SLEEP (**X**).
4. To communicate data from **LoRa Cloud** including GNSS requests, clock sync requests and almanac updates.

Each DL must be sent on the appropriate downstream port. The DL streams supported by CHICKADEE SW are shown in Table 3-1.

Table 3-1: DL Information Streams

Data Type	Sent on LoRaWAN Port [decimal]
Putting sensor into DEEP SLEEP (**X**)	**99**
Configuration and control commands (**R**/**W**/**X**)	**100**
LoRa Cloud communications	**192/199**

3.3.1 Entering DEEP SLEEP Command (*LoRaWAN Port 99* DL)

A DL can be sent to remotely put the sensor into DEEP SLEEP mode. The frame payload must contain the single byte **0x 00** and the DL must be sent on **LoRaWAN port 99**.

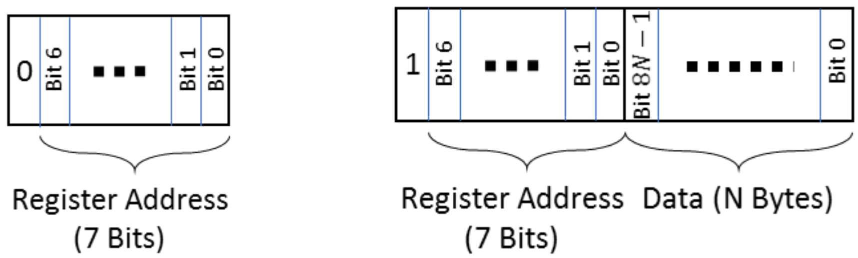
3.3.2 Configuration and Control Commands (*LoRaWAN Port 100* DLs)

All DL configuration and control commands are sent on **LoRaWAN port 100**. These commands involve accessing one or more configuration register to perform R, W, or X (executable) operations[14].

A single DL configuration and control payload can contain multiple command blocks, with a possible mix of R/W/X commands. Each message block is formatted as shown in Figure 3-4. A big-endian format (MSb/MSB first) is always followed. The sensor always processes command blocks in order from MSB to LSB, except configuration and control operations are processed last.

[13] Here “DLs” means “SW application-layer DLs” and “LR1110 middleware DLs;” there are other MAC-layer DLs that the NS may send to perform LoRaMAC operations. LoRaMAC behaviour occurs according to the LoRaWAN specifications and is outside the scope of this document [1].

[14] See §3.1 for general information about configuration registers.



a) Read Command Block (b) Write or Executable Command Block

Figure 3-4: The DL Formats for Configuration and Control Message Blocks

Bit 7 of the first byte determines whether a read or write action is being performed, as shown in Figure 3-4.

- **Read commands** are 1-byte where bit 7 is set to 0 and bits 0-6 are the register address being accessed. Data following a read access command will be interpreted as a new command block. Read commands are processed last. For example, in a single DL message, if there is a read command from a register and a write command to the same register, the write command is executed first.
- **Write or executable commands** begin with 1-byte where bit 7 is set to 1 and bits 0-6 are the register address being accessed. The first byte is followed by *N* bytes with the user-specified value to write to that register. The value *N* depends on the size of the value attributed to each register.

The sensor always processes the command blocks one-at-a-time in order from MSB to LSB with 2 exceptions:

- General command-and-control operations are processed last, and in the following order. See §4.4.
  1. Save configuration settings to flash.
  2. Reset configuration settings to factory default.
  3. Reset sensor.
- Switching between BLE modes: When a command to switch modes is present in the DL, the sensor immediately stops processing other command blocks and switches modes as described in §6.3.

When a sensor processes a command block that is trying to access a register bit designated as RFU or trying to write an invalid value to a register, no further command blocks are processed. Command-and-control operations are also not performed. The sensor responds with a message as described in §3.2.3.

For a complete summary list of the specific definitions, sizes, and default values of all configuration registers that are accessible by configuration and control commands, see Table A2-1 in Appendix 2 . These details are also included in the corresponding function-specific sections:

- LoRaMAC Options|§4.1.2
- Periodic Report Scheduling|§4.2.2
- Battery Management|§4.3.3
- General Command and Control Operations|§4.4.1
- Geolocation and GNSS|§5.1.3
- BLE Tracker Mode|§6.1.3
- BLE Beacon Mode|§6.2.2
- Differences between BLE Modes|§6.3.2
- Accelerometer|§7
- MCU Temperature Sensing|§8

3.3.3 LoRa Cloud Communications (LoRaWAN Port 192 and 199 DLs)

In the downlink direction, **LoRaWAN ports 192** and **199** are used for LoRa Cloud positioning information (ports 192) and device management (port 199). These processes occur according to the specifications of LoRa Cloud [3]. The behaviour is not configurable and therefore outside the scope of this document.

For port 199, downlinks from LoRa Cloud with clock sync information begin with 0x **00 20**, and downlinks from LoRa Cloud with almanac information (pages) begin with 0x 01 00 **0A**.

4 Basic Operation

The basic functionality of CHICKADEE can be broken down into the following categories:

- **LoRaMAC Options**: LoRaWAN general parameters and behaviour as defined by the LoRaWAN Specifications [1].
- **Periodic Report Scheduling**: Scheme for scheduling regular sensor data reports.
- **Battery Management**: Keeping track of consumed battery charge.
- **General Command and Control Operations**: Reading SW metadata, saving configuration settings, resetting to factory default, and sensor restart.

In the following subsections, the operational descriptions, report formats, and configurable settings for each category are explained.

4.1 LoRaMAC Options

4.1.1 Operational Description

The LoRaMAC options control certain LoRaWAN-specified MAC configuration parameters that the sensor loads on start-up and uses during run-time. The definitions for these parameters are stipulated by the LoRaWAN Specifications and Regional Parameters [1] [4]. Refer to these sources for detailed descriptions of these parameters and expected behaviour, as this is outside the scope of this TRM.

4.1.2 Configuration Settings

Table 4-1 shows the MAC configuration registers. In this table, the bit indexing scheme is as shown in Figure 3-1. To access these registers, a command must be formatted and sent according to the details described in §3.3.2.

Table 4-1: LoRaMAC Options Configuration Registers

Address	Name	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 11	Options	2 B	Access: R/W (bits 1 and 2 are RO) • Bit 0: 0/1 = Unconfirmed/Confirmed UL • Bit 1 = 1 (RO): 0/1 = Private/Public Sync Word • Bit 2 = 1 (RO): 0/1 = Duty Cycle disabled/enabled • Bit 3: 0/1 = Disable/Enable ADR • Bits 4-15: RFU	• Unconfirmed UL • Public Sync Word • Duty cycle enabled • ADR disabled **0x 00 06**	*loramac_opts: {* *confirm_mode: <value>, (unsigned/no unit)* *sync_word: <value>, (unsigned/no unit)* *duty_cycle: <value>, (unsigned/no unit)* *adr: <value> (unsigned/no unit)* *}*

Address	Name	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 12	DR and Tx Power[15]	2 B	Access: R/W • Bits 8-11: Default DR number • Bits 0-3: Default Tx power number, *m* • Bits 4-7, 12-15: RFU	• DR3 • Tx Power 0 (max power; see Table 4-2) **0x 03 00**	*loramac_dr_tx: {* *dr_number: <value>, (unsigned/no unit)* *tx_power_number: <value> (unsigned/no unit)* *}*

Table 4-2: Default Max Tx Power by Region

RF Region	Max Tx EIRP[16] [dBm]
EU868	15
US915	14

Note: Modifying these LoRaMAC settings only changes them in the sensor; LoRaMAC setting in the NS may also need to be changed depending on the desired use case and to ensure a sensor is not stranded without being able to communicate with the network. Modifying configuration parameters in the NS is outside the scope of this document.

4.1.2.1 Example DL Payloads

- Disable ADR, keep Duty Cycle enabled, and use confirmed ULs:
  - DL payload: **0x 91 00 07**
    - Register 0x 11 with bit 7 set to 1 = 0x 91
    - Desired options: register value with bit 3 set to 0, bit 2 set to 1, bit 1 set to 1, and bit 0 set to 1 = 0x 00 07
- Set default DR number to 3, default Tx power number to 4, and read back:
  - DL payload: **0x 92 03 04 12**
    - Register 0x 12 with bit 7 set to 0 = 0x 92
    - DR3 = 0x 03
    - Tx 4 = 0x 04
    - Register 0x 12 with bit 7 set to 0 = 0x 12

[15] Tx power number *m* translates to the maximum Tx power, which is a function of the LoRaWAN RF region, minus $2 \times m$ dB [1].

[16] These are Tx power *setpoints* and are the maximum allowable by the LoRaWAN regional parameters specification [1]. The actual Tx power of the sensor is limited by the radio transceiver, which is 14 dBm. Therefore, a setpoint greater than 14 dBm will be equivalent to a setpoint of 14 dBm or the Max Tx EIRP for the region, whichever is lower.

4.2 Periodic Report Scheduling

4.2.1 Operational Description

All periodic reporting of sensor data is synchronized around ticks. The *core tick* is simply a user-configurable time base unit that is used to schedule sensor measurements. For each transducer or subsystem in the sensor, the number of elapsed ticks between data transmissions is configurable. These reporting periods are defined by the following equation:

<Data Type> *Reporting Period* = *Seconds per Core Tick* × *Ticks per* <Data Type>

The available options for periodically reported data types are listed below. That is, <Data Type> can be:

- **Battery**: Remaining capacity [%], remaining lifetime [days], or both. See §4.3 for battery management details.
- **Geolocation Update:** The results from a geolocation scan cycle**.** The results sent depend on which scan technologies are enabled and can include:
  - LPGNSS raw scan data for LoRa Cloud.
  - GNSS raw scan data.
  - Discovered Wi-Fi access point MAC addresses and RSSIs [dBm].
  - Discovered BLE device MAC addresses and RSSIs.

  Two different update periods can be defined; one that is used when the sensor is in the MOBILE state and the other when in STILL. See §7.4 for how motion and stillness are detected.
- **Accelerometer**: Acceleration vector [*g*]. See §7 for accelerometer operation details.
- **MCU Temperature**: Temperature of the MCU [°C]. See §8 for temperature sensing details.

Seconds per Core Tick cannot be set to 0; periodic transmissions cannot be globally disabled.

If <Data Type> *Reporting Period* equals 0, it means that periodic reporting is disabled for that data type. Since *Seconds per Core Tick* cannot be set to 0, the above equation can only equal 0 when *Ticks per* <Data Type> is equal to 0. Therefore, to disable the periodic reporting of a specific data type, set its *Ticks per* <Data Type> to 0.

The default reporting behaviour is:

- 1 battery report per day.
- 1 geolocation report per hour while not moving.
- 1 geolocation report per 10 minutes while moving.
- 1 geolocation report per 4 minutes while in EMERGENCY.
- 1 temperature report per hour.

NOTE 1: These settings only control the scheduling of reporting data, not *what* is reported; the format and/or content of the reported payloads may depend on other configuration settings. Additionally, the periodic report scheduling settings only affect *periodic* reporting behaviour and do not affect *event-based* reporting behaviour. To configure behaviour not related to the scheduling of reports, refer to the relevant sections for the subsystem or transducer being used.

NOTE 2: It is not recommended to set the geolocation update period to **less than 3.5 min**. See §5.1.3.3 for guidelines on best practices for periodic configuration. The report period is controlled by registers 0x 20 (Core Tick), 0x 22 (Ticks per Geolocation Update in STILL state) and 0x 23(Ticks per Geolocation Update in MOBILE state).

NOTE 3: The first periodic report for every enabled report type occurs right after the sensor successfully joins the network. That is, tick 1 occurs right after successful join. A consequence of this is that, using the default battery reporting configuration as an example, the first battery report will occur immediately after join but the next one will occur 23 hours later (every report thereafter will occur at the expected 24-hour intervals).

4.2.1.1 Anti-Bricking Strategy

As a Class-A LoRaWAN end-device, the sensor can only receive a DL in the short period after sending an UL. Therefore, if the sensor is configured to send periodic ULs very infrequently or not at all, it could become impossible to send a DL command. A sensor in a “stranded” state like this is referred to as *bricked*.

CHICKADEE has the ability to manually force a UL by pressing the Function Button which cannot be disabled, so it is impossible to *completely* brick a sensor. However, there are use cases in which using the function button to trigger the sensor may not be a convenient option, e.g., due to special mounting orientation, remote location, or in the case of reconfiguring many devices at once. In these use-cases, a strategy to avoid bricking the sensor is beneficial and therefore included as a SW feature.

The anti-bricking strategy is summarized by the following statement:

The Battery Reporting Period cannot be set to a value greater than 1 day.

Consequently, it is impossible to completely disable periodic reporting. This is accomplished by restricting acceptable values of the tick registers. Specifically:

1. Register 0x 20: *Seconds per Core Tick* cannot be set to 0.
   This ensures that all periodic reporting cannot be disabled at once.
2. The equation in §4.2.1 must be nonzero and less than or equal to 1 week (604 800 s) for the battery report. This ensures that at a minimum, the sensor will send a battery report UL once per week. That is, the following must be true:

$$\textbf{Battery Reporting Period} = \textbf{Seconds per Core Tick} \times \textbf{Ticks per Battery}$$

$$0 < \textit{Battery Reporting Period} \leq 1 \text{ week}$$

$$0 < \textit{Battery Reporting Period} \leq 604\,800 \text{ s}$$

If the SW detects that a configuration has been set which does not satisfy the above condition, the *Ticks per Battery* is automatically set to $\left\lfloor \frac{604\,800 \text{ s}}{\textit{Seconds per Core Tick}} \right\rfloor$.

4.2.2 Configuration Settings

Table 4-3 lists the registers used to configure the periodic reporting periods. *Seconds per Core Tick* is configured using register 0x 20, and the *Ticks per* <Data Type> are configured using registers 0x 21 through 0x 26. In this table, the bit indexing scheme is as shown in Figure 3-1. To access these registers, a command must be formatted and sent according to the details described in §3.3.2.

Table 4-3: Periodic Report Scheduling Configuration Registers

Address	Value	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 20	Seconds per Core Tick	4 B	Access R/W • Tick value for periodic events • Acceptable values: 15, 16, 17, …, 86400 • Other values: Invalid and ignored	60 s = 1 min **0x 00 00 00 3C**	*seconds_per_core_tick: <value>* *(unsigned/s)*
0x 21	Ticks per Battery	2 B	Access R/W • Ticks between battery reports • Acceptable values: 1, 2, 3, …, 65535 • 0: Invalid and ignored	1440 ticks = 1 day period **0x 05 A0**	*ticks_per_battery: <value>* *(unsigned/no unit)*
0x 22	Ticks per Geolocation Update in STILL State	2 B	Access R/W • Ticks between geolocation scan cycles when the sensor is not in motion • Acceptable values: 0, 1, 2, …, 65535 • 0 disables periodic geolocation updates when not in motion	60 ticks = 1 hr period **0x 00 3C**	*ticks_per_geolocation_update_stillness: <value>* *(unsigned/no unit)*
0x 23	Ticks per Geolocation Update in MOBILE State	2 B	Access R/W • Ticks between geolocation scan cycles when the sensor is in motion • Acceptable values: 0, 1, 2, …, 65535 • 0 disables periodic geolocation updates when in motion	10 ticks = 10 min period **0x 00 0A**	*ticks_per_geolocation_update_mobility: <value>* *(unsigned/no unit)*

Address	Value	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 24	Ticks per Geolocation Update in EMERGENCY State	2 B	Access R/W • Ticks between geolocation scan cycles when the sensor is in EMERGENCY state • Acceptable values: 0, 1, 2, …, 65535 0 disables periodic geolocation updates when in EMERGENCY state	4 ticks = 4 min period **0x 00 04**	*ticks_per_geolocation_update_emergency: <value> (unsigned/no unit)*
0x 25	Ticks per Accelerometer	2 B	Access R/W • Ticks between accelerometer vector reports • Acceptable values: 0, 1, 2, …, 65535 • 0 disables periodic accelerometer vector reports	Periodic reporting disabled **0x 00 00**	*ticks_per_accelerometer: <value> (unsigned/no unit)*
0x 26	Ticks per Temperature	2 B	Access R/W • Ticks between MCU temperature reports • Acceptable values: 0, 1, 2, …, 65535 • 0 disables periodic temperature reports	60 ticks = 1 hr period **0x 00 3C**	*ticks_per_MCU_temp: <value> (unsigned/no unit)*

4.2.2.1 Example DL Payloads

- Change core tick to 1 hour:
  - DL payload: **0x A0 00 00 0E 10**
    - Register 0x 20 with bit 7 set to 1 = 0x A0
    - Seconds per Core Tick = 3 600 = 0x 00 00 0E 10
- Read current value of Seconds per Core Tick:
  - DL payload: **0x 20**
    - Register 0x 20 with bit 7 set to 0 = 0x 20
- Change settings to update the geolocation every 5 minutes regardless of motion state:
  - DL payload: **0x A0 00 00 00 3C A2 00 05 A3 00 05**
    - Register 0x 20 with bit 7 set to 1 = 0x A0
    - Seconds per core tick = 60 s = 0x 00 00 00 3C
    - Register 0x 22 with bit 7 set to 1 = 0x A3
    - Ticks per geolocation update in STILLNESS = 5 ticks = 0x 00 05
    - Register 0x 23 with bit 7 set to 1 = 0x A3
    - Ticks per geolocation update in MOBILITY = 5 ticks = 0x 00 05

4.3 Battery Management

4.3.1 Operational Description

CHICKADEE has a battery management system that monitors battery energy depletion.

The *remaining battery capacity* is the percentage of battery energy still available to the sensor relative to a fully charged battery. The SW always keeps track of this value, which gradually drops throughout normal operation. The rate at which the capacity drops depends on configuration; for example, a sensor configured to send a UL report every 15 min will have a larger energy consumption rate than one that is configured to send a UL report every 60 min.

The *remaining battery lifetime* is the estimated number of days remaining before the battery dies. The SW estimates this value, which may fluctuate up and down throughout the normal operation of the sensor. This is because configuration settings can be changed at any time during normal operation, thus changing the energy consumption rate.

The sensor sends battery reports at a configurable period. The default battery report period is 24 hours.

The data type reported is configurable and can be the remaining battery capacity, remaining battery lifetime, or both. By default, both values are reported. The UL report format is always as described in §4.3.2, regardless of whether it is a periodic or event-based report.

NOTE 1: The JOIN procedure consumes energy at a higher rate than default normal operation, so the remaining lifetime value reported will be skewed for some time after the sensor joins the network. It will take approximately 1 week over which “steady state” energy consumption occurs before the remaining battery lifetime values stabilize.

4.3.1.1 Resets and Fully Charged Battery

The battery management system bases calculations on the average nominal battery capacity of a charged battery. When the battery is recharged, the remaining battery capacity and lifetime values are automatically reset. Any hard reset (i.e., any complete loss of power) will result in the battery management system resetting.

Battery management data will not reset when a soft reset occurs (i.e., reset button press, OTA reset command, or Tracker/Beacon Mode switch occurs).

4.3.2 UL Report Frame Formats

Battery reports are sent on ***LoRaWAN port 10*** and have the frame format as shown in Figure 3-2. The specific details for the battery report frame formats are listed in Table 4-4. For the general description of sensor data report formats and behaviour, see §3.2.1.

Table 4-4: Battery Report UL Frame Formats

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Remaining Battery Capacity	0x 00	0x D3	1 B	Percentage	1% / LSb (unsigned)	*rem_batt_capacity: <value> (unsigned/%)*
Remaining Battery Lifetime	0x 00	0x BD	2 B	Days	1 day / LSb	*rem_batt_days: <value> (unsigned/days)*

4.3.2.1 Example UL Payloads

- **0x 00 D3 32 00 BD 01 E6**
  - Channel ID = 0x 00, Type ID = 0x D3 → remaining battery capacity data report
  - 0x 32 = 50 × 1% = 50%
  - Channel ID = 0x 00, Type ID = 0x BD → remaining battery lifetime data report
  - 0x 01 E6 = 486 × 1 day = 486 days

4.3.3 Configuration Settings

All configuration registers that control battery management behaviour are listed in Table 4-5. In this table, the bit indexing scheme is as shown in Figure 3-1. To access these registers, a command must be formatted and sent according to the details described in §3.3.2.

Table 4-5: Battery Management Configuration Registers

Address	Name	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 20	Seconds per Core Tick	4 B	Access R/W • Tick value for periodic events • Acceptable values: 15, 16, 17, …, 86400 • Other values: Invalid and ignored	60 s = 1 min **0x 00 00 00 3C**	*seconds_per_core_tick: <value> (unsigned/s)*
0x 21	Ticks per Battery	2 B	Access R/W • Ticks between battery reports • Acceptable values: 1, 2, 3, …, 65535 • 0: Invalid and ignored	1440 ticks = 1 day period **0x 05 A0**	*ticks_per_battery: <value> (unsigned/no unit)*

Address	Name	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 4A	Battery Report Options	1 B	Access: R/W • Bit 1: 0/1 = Remaining battery capacity [%] not reported/reported • Bit 2: Remaining battery lifetime [days] not reported/reported • Bits 1-2 all set to 0: Invalid • Bits 0, 3-7: RFU	Remaining battery capacity [%] and remaining battery lifetime [days] reported **0x 06**	*battery_tx: { report_capacity_enabled: <value>, (unsigned/no unit) report_lifetime_enabled: <value> (unsigned/no unit) }*

4.3.3.1 Periodic Reporting Configuration

The battery reporting period can be configured using registers 0x 20 and 0x 21 according to the equation described in §4.2.2. That is:

$$\textit{Battery Reporting Period} = \textit{Seconds per Core Tick} \times \textit{Ticks per Battery}$$

Setting the battery reporting period to 0 disables periodic reporting of battery management data.

4.3.3.2 Operational Configuration

Register 0x 4A determines what type of data is reported at the time a battery report is due.

4.3.3.3 Example DL Payloads

- Schedule a battery report every 48 hours:
    - DL payload: **0x A0 00 00 0E 10 A1 00 30**
        - Register 0x 20 with bit 7 set to 1 = 0x A0
        - 3600 s/core tick = 0x 00 00 0E 10
        - Register 0x 21 with bit 7 set to 1 = 0x A1
        - Report every 48 ticks = 0x 00 30
- Only include remaining battery capacity in battery reports:
    - DL payload: **0x CA 02**
        - Register 0x 4A with bit 7 set to 1 = 0x CA
        - Value bit 1 set to 1 = 0x 02

4.4 General Command-and-Control Operations

4.4.1 List of Operations and Register Values

The general command and control operations supported by CHICKADEE are:

- Saving the current configuration settings to flash memory.
- Restarting the sensor (soft reset).
- Reading FW and BLE metadata (SW version numbers).
- Factory reset of configuration settings.

To perform a command-and-control operation, the appropriate register must be accessed. Table 4-6 lists the details of the command-and-control registers. In this table, the bit indexing scheme is as shown in Figure 3-1. To access these registers, a command must be formatted and sent according to the details described in the following subsections and in §3.3.2.

Table 4-6: Command & Control Register Details

Address	Access	Name	Size	Description and Options	JSON Variable (Type/Unit)
0x 70	X	Flash Write Command	2 B	• Bit 14: 0/1 = Do not write/Write LoRaMAC Configuration • Bit 13: 0/1 = Do not write/Write App Configuration • Bit 0: 0/1 = Do not restart/Restart Sensor • Bits 1-12, 15: RFU (0, otherwise invalid)	*write_to_flash {* *app_config: <value>, (unsigned/no unit)* *lora_config: <value>, (unsigned/no unit)* *restart_sensor: <value> (unsigned/no unit)* *}*

Address	Access	Name	Size	Description and Options	JSON Variable (Type/Unit)
0x 71	RO	FW Metadata	7 B	• Bits 48-55: App version major • Bits 40-47: App version minor • Bits 32-39: App version revision • Bits 24-31: LoRa Basics modem version major • Bits 16-23: LoRa Basics modem version minor • Bits 8-15: LoRa Basics modem version revision • Bits 0-7: LoRaMAC region number[17]	*metadata {* *app_ver_major: <value>, (unsigned/no unit)* *app_ver_minor: <value>, (unsigned/no unit)* *app_ver_revision: <value>, (unsigned/no unit)* *modem_ver_major: <value>, (unsigned/no unit)* *modem_ver_minor: <value>, (unsigned/no unit)* *modem_ver_revision: <value>, (unsigned/no unit)* *loramac_region: <value> (unsigned/no unit)* *}*
0x 72	X	Reset Configuration to Factory Defaults	1 B	• 0x 0A: Reset app configuration • 0x B0: Reset LoRaMAC configuration • 0x BA: Reset both App and LoRaMAC configurations • Any other value: Invalid and ignored	*config_factory_reset {* *app_config: <value>, (unsigned/no unit)* *loramac_config: <value> (unsigned/no unit)* *}*
0x 73	RO	BLE Metadata	6 B	• Bits 16-23: BLE stack version major • Bits 8-15: BLE stack version minor • Bits 0-7: BLE stack version revision • Bits 24-47: RFU	*ble_metadata {* *stack_ver_major: <value>, (unsigned/no unit)* *stack_ver_minor: <value>, (unsigned/no unit)* *stack_ver_revision: <value>, (unsigned/no unit)* *}*

[17] Defined by Table 4-7.

4.4.2 Save Current Configuration Settings

Configuration changes are not retained after a power cycle (soft or hard reset) unless they are saved in the non-volatile flash memory. To do so, the *Flash Write Command* register, 0x 70, must be accessed to execute the save-to-flash operation.

The DL payload structure is as shown in Figure 3-4. That is, with the first byte being the register address with bit 7 set to 1 (i.e., 0x F0) and the data indicating which options are selected of those listed in Table 4-6. Specifically, the payloads for the different save options (without restarting the sensor) are:

- **0x F0 20 00**: Save current configuration settings of all FW application registers (0x 20 through 0x 6F) to flash.
- **0x F0 40 00**: Save current configuration settings of all FW LoRaMAC Option registers (0x 11 and 0x 12) to flash.
- **0x F0 60 00**: Save current configuration settings of both FW application and LoRaMAC Options registers to flash.

The save-to-flash command can be sent in a separate DL at any time or be included in the same payload as other read and write command blocks. In the latter case, all other command blocks are always executed first, so that settings can be changed and saved in a single payload.

Register 0x 70 also supports a reset option, described in §4.4.3. When this option is not selected, the sensor will send a write response (as described in §3.2.3) after receiving the flash write command.

4.4.3 Sensor Restart

The *Flash Write Command* register, 0x 70, is used to restart the device via soft reset.

This is done by setting bit 0 to 1. This can be used alone or in conjunction with any of the save-to-flash operation options listed in §4.4.2 above. In the former case, the explicit payload is **0x F0 00 01**.

Immediately after receiving the reset command in a DL, the sensor will reset.

NOTE: Do not send the reset command as a confirmed DL. The reset command causes the sensor to restart before it can send the acknowledgement UL in response. The sensor will rejoin the network but then get the command sent again from the NS, causing a loop of continual rebooting[18].

[18] Some network servers, including TEKTELIC's KONA Core, have an optional setting to clear the DL queue upon receiving a JOIN REQUEST for a new session. This is an alternative solution if confirmed DLs are required.

4.4.4 Read FW and BLE Metadata

The *FW Metadata* register, 0x 71, can be accessed to read the *application version number*, *LoRa Basics modem version number*, and *LoRaMAC region number*. The *BLE Metadata* register, 0x 73, can similarly be accessed to read the *BLE stack version number.*

The read metadata command is formulated as a regular read command as shown in Figure 3-4. Explicitly, the command blocks in the payload would be **0x 71** for FW and **0x 73** for BLE.

After receiving one of these commands, the sensor will respond with a UL message containing the following:

- For FW metadata:
  - The fist byte is the register address: 0x 71.
  - Bits 32 to 55 of the value contain the application revision numbers which define the FW version. The FW version is reported in the format as shown in Figure 4-1, which is shown using the example FW v1.0.15 (value 0x 01 00 0F).

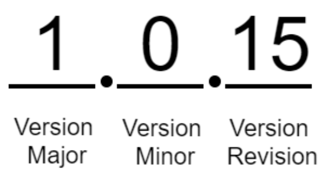


Figure 4-1: Example FW Version Format

  - Bits 8 to 31 of the value contain the LoRa Basics modem version numbers. The format is the same as shown in Figure 4-1. This number is not to be confused with the LoRaWAN specification version according to the LoRa Alliance standards. The LoRaMAC version number is the version of the FW used by the LR1110.
  - The last byte contains the LoRaMAC region number. Current LoRaMAC regions and corresponding region numbers for the sensor are listed in Table 4-7.

Table 4-7: LoRaMAC Regions and Region Numbers

LoRaMAC Region	Region Number
EU868	0
US915	1
AS923	2
AU915	3
IN865	4
KR920	6
RU864	7

- For BLE metadata:
  - The fist byte is the register address: 0x 73.
  - Bits 0 to 23 of the value contain the BLE stack version numbers. The BLE stack is the SW published by Bluetooth and not developed by TEKTELIC. The version is reported in the format as shown in Figure 4-1.

4.4.5 Factory Reset

The *Reset Configuration to Factory Defaults* register, 0x 72, is used to reset all the configuration register values (0x 10 to 0x 6F) back to the default settings.

The DL payload structure is as shown in Figure 3-4. That is, with the first byte being the register address with bit 7 set to 1 (i.e., 0x F2) and the data indicating which options are selected of those listed in Table 4-6. Specifically, the payloads for the different factory reset options are:

- **0x F2 0A**: Restore configuration settings of all FW application registers (0x 20 to 0x 5C) to factory default values.
- **0x F2 B0**: Restore configuration settings of all FW LoRaMAC Options registers (0x 10 to 0x 13) to factory default values.
- **0x F2 BA**: Restore configuration settings of both FW application and LoRaMAC Options registers to factory default values.

The factory command can be sent in a separate DL at any time or be included in the same payload as the other read and write command blocks. In the latter case, only the factory command block is executed while all other commands are discarded.

After receiving the factory reset command, the sensor always restarts immediately.

NOTE: Do not send the factory reset command as a confirmed DL. The command causes the sensor to restart before it can send the acknowledgement UL in response. The sensor will rejoin the network but then get the command sent again from the NS, causing a loop of continual rebooting[19].

[19] Some network servers, including TEKTELIC's KONA Core, have an optional setting to clear the DL queue upon receiving a JOIN REQUEST for a new session. This is an alternative solution if confirmed DLs are required.

5 Geolocation Operation

The primary purpose of CHICKADEE is location tracking both indoors and outdoors using a combination of location-tracking technologies:

- ***GNSS:*** Outdoor tracking using satellite geolocation with the ublox (MAX-M10S) transceiver.
- ***LPGNSS:*** Outdoor tracking using satellite geolocation with the LR1110 transceiver.
- ***Wi-Fi Sniffing:*** Outdoor and/or indoor tracking using Wi-Fi access point geolocation.
- ***BLE Tracking:*** Indoor tracking using BLE beacon network localization.

GNSS is used upon entering the EMERGENCY state, and until exiting the EMERGENCY state.

The raw data collected during each scan is sent in a LoRaWAN payload and can be forwarded to an application layer which uses cloud resolver services (only in the case of LPGNSS) to calculate the estimated sensor location.

In the following subsections, the operational descriptions, report formats, and configurable settings for different geolocation strategies are explained.

5.1 Scan Cycle and Resolving LPGNSS, GNSS, Wi-Fi, and BLE Locations

5.1.1 Operational Description

CHICKADEE conducts one or more geolocation scans during its *geolocation cycle*. A new geolocation cycle occurs at a regular period called the *geolocation update period*, as shown in Figure 5-1. By default, the geolocation update period is shorter when the sensor is in motion and longer when the sensor is still[20]. These periods are configurable as described in §5.1.3.

LPGNSS is chosen by default for NORMAL operation mode. See Table 5-5 for the configuration settings.

[20] See §7.4 for how the accelerometer detects motion to help change the geolocation update period.

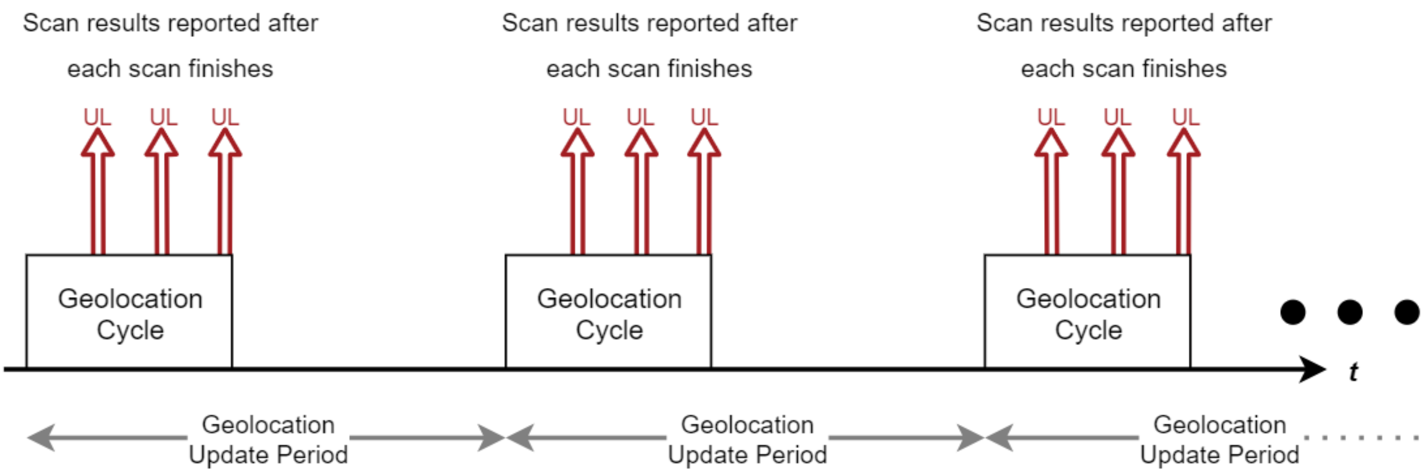


Figure 5-1: Periodic Geolocation Cycles and ULs

During a geolocation cycle, up to 3 scans can be defined and occur in sequence. After each scan concludes, if successful, the raw results are reported in a LoRaWAN UL before the next scan begins[21].

The duration of each geolocation cycle may vary from 10's of seconds to a few minutes, depending on several factors (e.g.: satellite signal strength, user configurable BLE scan duration, regional duty cycle limitations, etc.). It is important to configure the geolocation update period to be greater than the expected geolocation cycle duration, otherwise the periodicity of reports may not be as expected. It is not recommended to set the geolocation update period **to less than 3.5 min**. If ONLY BLE scanning is enabled, it is not recommended to set the geolocation update to less than 20 s. See §5.1.3.3 for guidelines on best practices for periodic configuration.

The supported scan type options and behaviours are summarized in Table 6-1.

[21] If sending BLE scan results is paused due to regional duty cycle restrictions, the next scan (GNSS or Wi-Fi), if defined, will not begin until the duty cycle timeout expires and the BLE results are sent.

Table 5-1: Supported Geolocation Scan Technologies

Technology	Function	Results Format	Scan Failure Behaviour	Configurable Options
LPGNSS	LR1110 performs a low-power GNSS scan, then sends the scan results via LoRaWAN UL for LoRa Cloud to compute the position.	NAV message or message fragments containing satellite information.	Fail criteria[22]: too few satellites are detected, almanac is out of date, or clock is out of sync. No UL is sent unless all other scans in the cycle also fail.	Assist coordinates
GNSS	MAX-M10S performs a GNSS scan, then sends the scan results via LoRaWAN UL	Message fragments containing satellite information.	Send a blank UL on port 10.	Switch primary geolocation scan technology (LPGNSS or GNSS)
Wi-Fi	LR1110 performs a Wi-Fi scan then sends the scan results via LoRaWAN UL for LoRa Cloud to compute the position.	Discovered Wi-Fi access point MAC addresses and RSSIs [dBm].	Fail criterion[22]: less than 3 Wi-Fi access points are discovered. No UL is sent unless all other scans in the cycle also fail.	None
BLE	MCU performs a BLE scan then sends the scan results via LoRaWAN UL for the GRB (Geolocation Resolver Backend) to compute the position.	Discovered BLE device MAC addresses and RSSIs [dBm].	Fail criterion: 0 BLE beacons detected. UL containing an empty list is sent.	• Scan duration • Scan duty cycle • Up to 4 discovered BLE device filters

The *scan order logic* within the geolocation cycle is also configurable to allow the cycle to end upon a successful scan before the other defined scans occur. Doing so can save battery life in use-cases where the scan types can be prioritized by how likely they are to succeed, e.g.: if it is known that GNSS will be the available geolocation signal source 90% of the time. The supported scan order logic options are shown in Table 5-2.

[22] The results of successful GNSS and Wi-Fi scan will fail to send if the sensor is restricted due to duty cycle at the time. Unlike other data reports, the scan results are dropped completely and not transmitted once the duty cycle timeout elapses. In these cases, if all other scans also fail, the *geolocation cycle failed* message will indicate this happened.

Table 5-2: Scan Order Logic Options

A:	1st scan	→	2nd scan if 1st scan fails	→	3rd scan if 2nd scan fails
B:	1st scan	→	2nd scan	→	3rd scan if 2nd scan fails
C:	1st scan	→	2nd scan if 1st scan fails	→	3rd scan
D:	1st scan	→	2nd scan	→	3rd scan

5.1.1.1 Geolocation Strategies

The ability to define up to 3 scan types and choose 1 of 4 scan order logic options results in 12 possible configurational combinations. This combination is called the *geolocation strategy*. Of the 12 geolocation strategies, only 7 result in unique device behaviour, as shown by the green shaded boxes in Table 5-3.

Table 5-3: Geolocation Strategies

Strategy Description	Scan Order Logic	Number of Defined Scans		
		3	2	1
FALLBACK • 1st priority scan always done. • Fallback to other scan(s) upon failure. • End cycle upon successful scan.	A	**#1**	**#2**	#7
1 BACKUP • 1st and 2nd priority scans always done. • 3rd scan if both 1st and 2nd scans failed.	B	**#3**	#6	#7
2 BACKUPS • 1st priority scan always done. • 2nd and 3rd scans done if 1st scan failed.	C	**#4**	#2	#7
ALL SCANS • All defined scans always done.	D	**#5**	**#6**	**#7**

The geolocation strategy used should be tailored to the use case of the CHICKADEE deployment. Some example use-cases and strategies are:

- **Outdoor remote worker: FALLBACK with (1) LPGNSS (2) Wi-Fi, (3) BLE**
  Likely to be outside for most of the time, so LPGNSS is likely to succeed most of the time. Wi-Fi is next most likely, then BLE.
- **Indoor worker: 2 BACKUP with (1) BLE, (2) Wi-Fi, (3) LPGNSS**
  Likely to be in an indoor BLE Beacon network most of the time, so BLE is likely to succeed most of the time. If BLE fails, try both other methods to get a position estimate.

The default geolocation strategy is fallback (scan order logic A) with all 3 scans defined in priority order LPGNSS, Wi-Fi, BLE. The operational flow of this strategy is depicted in Figure 5-2. All other strategy flow depictions are shown in Appendix 3.

With all geolocation strategies, if all scans fail, the *geolocation cycle failed* message is sent.

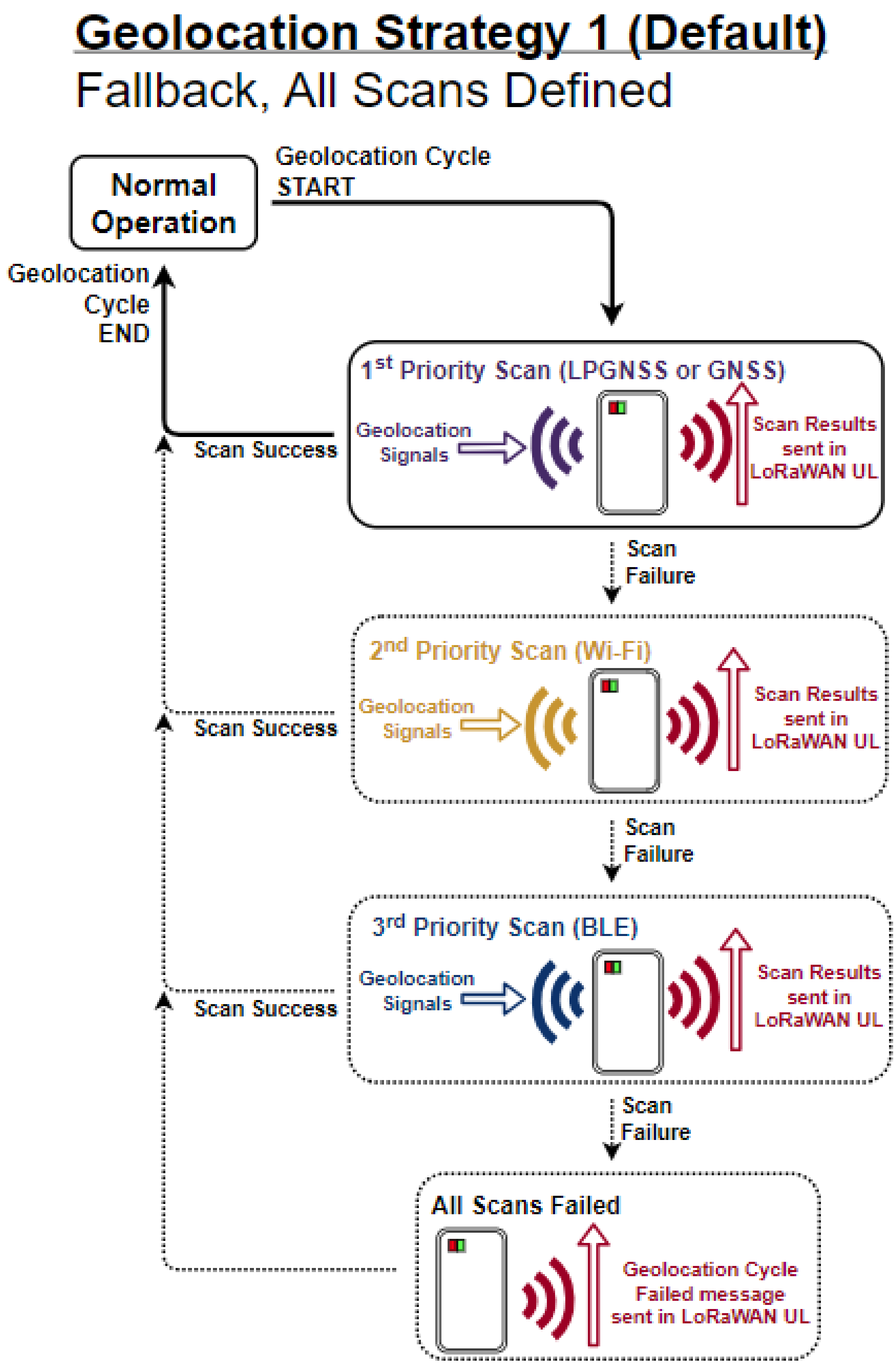


Figure 5-2: Default Geolocation Strategy Cycle Flow

5.1.1.2 LPGNSS and Wi-Fi Operation with LoRa Cloud Resolvers

The LPGNSS and Wi-Fi scan results are formatted in such a way that the edge based LoRa Cloud service can resolve the sensor's position. Both UL and DL communications are exchanged between CHICKADEE and LoRa Cloud server to transfer all the information needed for the positions to be resolvable.

For LPGNSS scan results to be valid and resolvable, the following are needed:

- **Valid clock synchronization**: The internal time of the sensor must be synchronized periodically. This is managed by LoRa Cloud.
- **Valid almanac**: The almanac in the sensor must be kept up to date. This is managed by LoRa Cloud.
- **Assist coordinates**: These help the resolver with an initial estimate of the sensor's location. These can be configured specifically by the user if desired, but the SW will automatically communicate with LoRa cloud to obtain assist coordinates upon startup if none are defined.

Wi-Fi scanning has no configurable options.

5.1.1.3 BLE Operation with LOCUS and the GRB

BLE scan results are formatted in such a way that the TEKTELIC LOCUS application can resolve and display the sensor's position. Indoor BLE beacon networks can be built virtually in LOCUS to match the physical setup. When LOCUS receives a sensor UL with raw BLE scan data, it forwards it to the *Geolocation Resolver Backend* (GRB) cloud service, which computes and returns the position estimate within the beacon network.

For information about setting up LOCUS, refer to the TEKTELIC support portal *Knowledge Base* article [6]. For a description of BLE scan behaviour, see §6.1.1.

5.1.2 UL Report Frame Formats

LPGNSS scan results are sent on **LoRaWAN port 192** and have the frame format shown in Figure 5-3. **Wi-Fi** scan results are sent on **LoRaWAN port 197** and have the frame format shown in Figure 5-4. Autonomous LoRa Cloud communication messages such as almanac update requests and updates are sent over **LoRaWAN port 199** (in both the upstream and downstream direction). For details about these messages and definitions of frame contents, refer to the LoRa Cloud documentation [3].

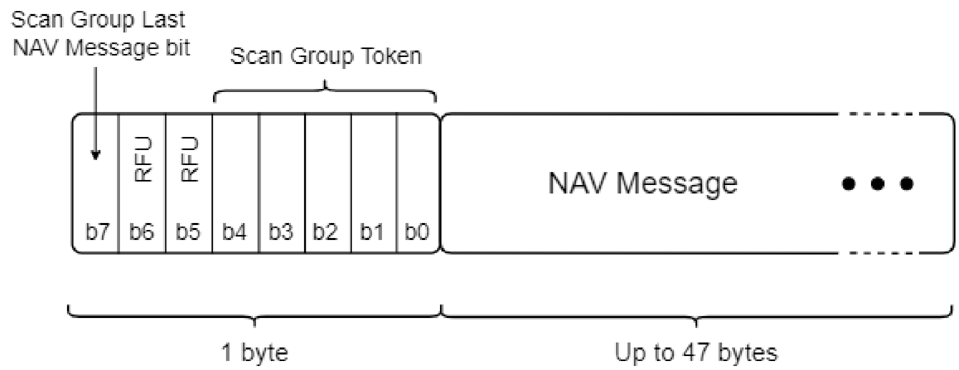


Figure 5-3: The LPGNSS Scan Results UL Frame Format

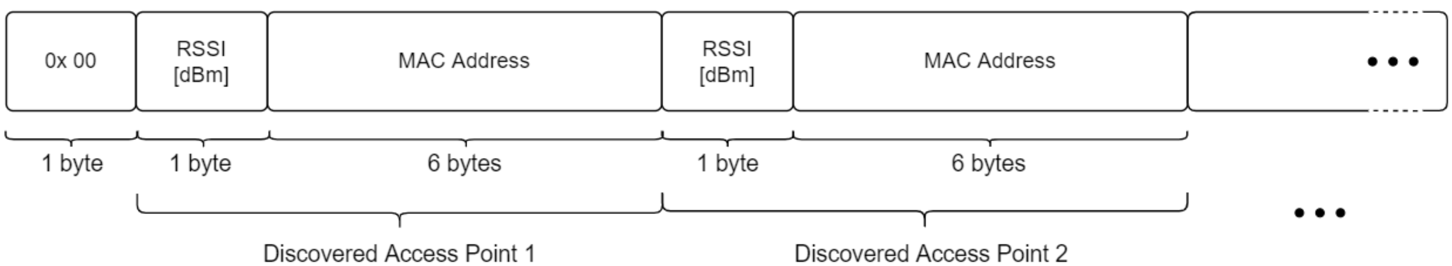


Figure 5-4: The Wi-Fi Scan Results UL Frame Format

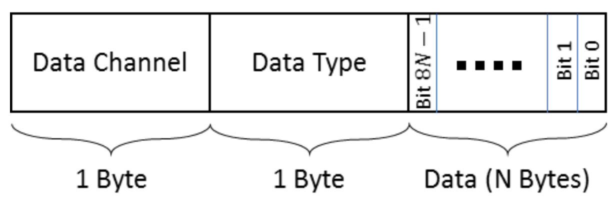


Figure 5-5: UL Frame Format for GNSS Report

BLE scan results are sent on **LoRaWAN port 25**. For a description of these report formats, see §6.1.2.

GNSS scan results are sent on **LoRaWAN port 10** and have the frame format shown in Figure 5-5. When GNSS scans are enabled, CHICKADEE performs multiple scans until a suitable position fix is acquired, with each scan lasting a non-configurable duration of four (4) seconds. These scans can last for a maximum non-configurable period of 210s per period before the CHICKADEE moves on to the next scan type defined in the geolocation cycle. If a suitable position fix is acquired before the 210s timeout, then the scan results are sent to the application.

Following a successful GNSS scan, CHICKADEE provides the following information:

1. Position Fix Coordinates:
    a. Latitude: The geographic coordinate that specifies the north–south position of a point on the Earth's surface. Latitude values range from -90.0 to +90.0 degrees.
    b. Longitude: The geographic coordinate that specifies the east-west position of a point on the Earth's surface. Longitude values range from -180.0 to +180.0 degrees.
    c. Altitude: the elevation above sea level, measured in meters.
2. Position Fix Timestamp (in UTC):
    a. Year: The year the position fix was acquired.
    b. Month: The month the position fix was acquired.
    c. Day: The day the position fix was acquired.
    d. Hour: The hour (in 24-hour format the position fix was acquired.
    e. Minute: The minute the position fix was acquired.
    f. Second: The second the position fix was acquired.
3. Groundspeed: the speed of the CHICKADEE device relative to the ground, measured in meters per second.

If all defined scans in a geolocation cycle fail, a *geolocation cycle failed* message is sent on **LoRaWAN port 10** and has the frame format as shown in Figure 3-2. The specific details are listed in Table 5-4 below. For the general description of sensor data report formats and behaviour, see §3.2.1.

Table 5-4: Geolocation Cycle Failed Report UL Frame Format

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Geolocation Cycle Failed	0x 00	0x 95	1 B	Bitmap Input	• Bits 0-1: LPGNSS Scan ○ 00: Scan failed ○ 11: Scan successful or scan not done • Bit 2: Wi-Fi scan ○ 0: Scan failed ○ 1: Scan successful or scan not done • Bit 3: BLE scan ○ 0: Scan failed ○ 1: Scan successful or scan not done • Bit 4: LoRaWAN duty cycle ○ 0: LPGNSS and/or Wi-Fi scan results dropped due to duty cycle restrictions ○ 1: No duty cycle restriction impacts • Bits 5-6: GNSS Scan ○ 00: Scan failed ○ 11: Scan successful or scan not done • Bit 7: 0 (RFU)	*geolocation_cycle_failed: {* *lpgnss: <value>, (unsigned/no unit)* *wi_fi: <value>, (unsigned/no unit)* *ble: <value>, (unsigned/no unit)* *duty_cycle: <value>, (unsigned/no unit)* *gnss: <value>, (unsigned/no unit)* *}*

5.1.2.1 Example UL Payloads

- **0x 00 95 10**
  - Channel ID = 0x 00, Type ID = 0x 95 → geolocation cycle failed message
  - 0x 10 = 0b 0001 0000 → All scans failed, no duty cycle impacts
- **0x 00 95 0F**
  - Channel ID = 0x 00, Type ID = 0x 95 → geolocation cycle failed message
  - 0x 0F = 0b 0000 1111 → GNSS and Wi-Fi scans were successful, but results were not sent due to duty cycle restrictions. BLE scan was not done (if it was done and was successful as bit 3 = 1 indicates, then the geolocation cycle failed message would not have been sent).

5.1.3 Configuration Settings

Table 5-5 shows the list of configuration registers which affect geolocation, LPGNSS and GNSS behaviour. In this table, the bit indexing scheme is as shown in Figure 3-1. To access these registers, a command must be formatted and sent according to the details described in §3.3.2. For BLE configuration, see §6.1.3.

Table 5-5: Geolocation Configuration Registers

Address	Name	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 20	Seconds per Core Tick	4 B	Access R/W • Tick value for periodic events • Acceptable values: 15, 16, 17, …, 86 400 • Other values: Invalid and ignored	60 s = 1 min **0x 00 00 00 3C**	*seconds_per_core_tick: <value>* *(unsigned/s)*
0x 22	Ticks per Geolocation Update in STILL State	2 B	Access R/W • Ticks between geolocation scan cycles when the sensor is not in motion • Acceptable values: 0, 1, 2, …, 65535 0 disables periodic geolocation updates when not in motion	60 ticks = 1 hr period **0x 00 3C**	*ticks_per_geolocation_update_stillness: <value>* *(unsigned/no unit)*
0x 23	Ticks per Geolocation Update in MOBILE State	2 B	Access R/W • Ticks between geolocation scan cycles when the sensor is in motion • Acceptable values: 0, 1, 2, …, 65535 0 disables periodic geolocation updates when in motion	10 ticks = 10 min period **0x 00 0A**	*ticks_per_geolocation_update_mobility: <value>* *(unsigned/no unit)*
0x 24	Ticks per Geolocation Update in EMERGENCY State	2 B	Access R/W • Ticks between geolocation scan cycles when the sensor is in EMERGENCY state • Acceptable values: 0, 1, 2, …, 65535 0 disables periodic geolocation updates when in EMERGENCY state	4 ticks = 4 min period **0x 00 04**	*ticks_per_geolocation_update_emergency: <value>* *(unsigned/no unit)*

Address	Name	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 30	Geolocation Strategy	1 B	Access: R/W • Bits 0-1: 1st priority scan ○ 01: BLE ○ 10: WIFI ○ 11: LPGNSS ○ 00: Invalid and ignored • Bits 2-3: 2nd priority scan ○ 00: Not defined ○ 01: BLE ○ 10: WIFI ○ 11: LPGNSS • Bits 4-5: 3rd priority scan ○ 00: Not defined ○ 01: BLE ○ 10: WIFI ○ 11: LPGNSS • Bits 6-7: Scan order logic option (see Table 5-2) ○ 00: A ○ 01: B ○ 10: C ○ 11: D • Restrictions: ○ 2nd scan must be defined to set 3rd scan ○ Scan types can only be defined once	• 1st priority scan: LPGNSS • 2nd priority scan: Wi-Fi • 3rd priority scan: BLE • Scan order logic option A **0b 00 01 10 11** or **0x 1B**	*geolocation_strategy: {* *scan_1: <value>, (unsigned/no unit)* *scan_2: <value>, (unsigned/no unit)* *scan_3: <value>, (unsigned/no unit)* *scan_order_logic: <value>, (unsigned/no unit)* *}*
0x 36	LPGNSS Assist Coordinates	8 B	Access: R/W • Bit 0: ○ 0/1: disable/enable assist coordinates • Bits 1-15: RFU • Bits 16-39: Longitude *y* [(180°/2^{23})/LSb ≈ 0.00002°/LSb] **Acceptable values: -180 ≤ *y* ≤ 180** • Bits 40-63: Latitude *x* [(90°/2^{23})/LSb ≈ 0.00001°/LSb] **Acceptable values: -90 ≤ *x* ≤ 90**	• Assist coordinates disabled • x = 0° • y = 0° **0x 00 00 00 00 00 00 00 00 00**	*assist_coordinates: {* *latitude: <value>, (signed/°)* *longitude: <value>, (signed/°)* *enabled: <value>, (unsigned/no unit)* *}*
0x 3F	GNSS Receiver	1 B	Access: R/W • 0x 00 = LPGNSS • 0x 01 = GNSS	LPGNSS **0x 00**	*gnss_receiver: <value> (unsigned/no unit)*

5.1.3.1 Periodic Scanning and Reporting Configuration

The geolocation update periods can be configured using registers 0x 20, 0x 22, and 0x 23 according to the equation described in §4.2.2. That is:

$$\textbf{\textit{STILL Geolocation Update Period}} = \textbf{\textit{Seconds per Core Tick}} \times \textbf{\textit{Ticks per Geolocation Update in STILL State}}$$

$$\textbf{\textit{MOBILE Geolocation Update Period}} = \textbf{\textit{Seconds per Core Tick}} \times \textbf{\textit{Ticks per Geolocation Update in MOBILE State}}$$

The *Accelerometer Assist* feature (described in §7.4) allows CHICKADEE to determine whether to use the STILLNESS or MOBILE geolocation update period depending on the motion state of the device. By default, CHICKADEE conducts a geolocation update cycle once every hour when still and once every 10 min while in motion.

As illustrated in Figure 5-1, the geolocation update period specifically defines the period between the starts of consecutive cycles, not the period between scan result ULs. The scan results are always sent in a LoRaWAN UL within 1 s at the conclusion of each scan, except in some cases when regional duty cycle limitations are in effect. Since the durations of each scan may vary, the scan results may be sent with irregular periods.

It is not recommended to set the geolocation update period **to less than 3.5 min**. If ONLY BLE scanning is enabled, it is not recommended to set the geolocation update to less than 20 s. See §5.1.3.3 for guidelines on best practices for periodic configuration.

Setting either geolocation update period to 0 disables periodic scanning and reporting when the device is in the corresponding motion state.

5.1.3.2 Operational Configuration

The geolocation strategy is determined through register 0x 30; bits 0-5 define the scan types and priorities, bits 6-7 define the scan order logic. Note that a change to this register is not immediate if there is a geolocation scan cycle taking place – the change will happen once the scan cycle has completed.

Register 0x 3F controls which GNSS receiver will be used in NORMAL mode; either GNSS (MAX-M10S) or LPGNSS (LR1110). **EMERGENCY mode will always use GNSS (MAX-M10S).**

5.1.3.3 Configuration Guidelines and Best Practices

As a class-A LoRaWAN end-device, CHICKADEE is meant to update its location infrequently (compared to real-time continuous geolocation trackers) to achieve a long battery life. The shorter the update periods are, the quicker the battery will be depleted.

Furthermore, because the geolocation cycle durations are nonzero and may vary, some configurations can result in the sensor not responding as desired. The general rule of thumb is that the geolocation scan durations plus the time to report the scan results should be smaller than the entire geolocation update period.

- The GNSS and Wi-Fi scan durations vary depending on factors out of the user's control, e.g., poor geolocation signal quality or an out-of-date almanac. These scans may take up to 90 s.

- The BLE scan duration is user configurable and can be up to 10 s. See §6.1.
- The report period is controlled by registers 0x 20 (Core Tick), 0x 22 (Ticks per Geolocation Update in STILL state) and 0x 23(Ticks per Geolocation Update in MOBILE state).
- The report period is a function of:
  - UL LoRaWAN DR and size of payload(s). For example, while a larger DR takes fewer packets to report a certain number of BLE or Wi-Fi devices, a smaller DR would require more packets for the same number. Moreover, due to LoRaWAN standard requirements, the packets cannot be sent out faster than about every 3 s [1].
  - Regional duty cycle restrictions. Some regions enforce limiting time-on-air. If sending is restricted at the time scan results are ready, the sending may be paused for up to 4 min.

As a result, although the geolocation update period can be configured to be as short as 15 s (this is the minimum value of core tick), it is not recommended to set the geolocation update period to **less than 3.5 min**. Setting the periods to less than 3.5 min may result in unexpected results, such as getting messages less often than expected.

5.1.3.4 Example DL Payloads

- Schedule a geolocation cycle and update every 15 min, regardless of motion state:
  - DL payload: **0x A0 00 00 00 3C A2 00 0F A3 00 0F**
    - Register 0x 20 with bit 7 set to 1 = 0x A0
    - 60 s/core tick = 0x 00 00 00 3C
    - Register 0x 22 with bit 7 set to 1 = 0x A2
    - Begin new cycle every 15 ticks when still = 0x 00 0F
    - Register 0x 23 with bit 7 set to 1 = 0x A2
    - Begin new cycle every 15 ticks when in motion = 0x 00 0F
- Configure the sensor to use geolocation strategy 5 (do all scans, every cycle) in the order BLE, GNSS, Wi-Fi:
  - DL payload: **0x B0 ED** (0b 1110 1101)
    - Register 0x 30 with bit 7 set to 1 = 0x B0
    - 1st priority scan = BLE
      - Value bits 0-1 set to 01
    - 2nd priority scan = LPGNSS
      - Value bits 2-3 set to 11
    - 3rd priority scan = Wi-Fi
      - Value bits 4-5 set to 10
    - Scan order logic option D
      - Value bits 6-7 set to 11

6 BLE Operation

Each CHICKADEE can operate in 1 of 2 *modes*:

- **Tracker Mode (default)**: The sensor conducts geolocation tracking as described in §5. With respect to BLE, if BLE scans are defined (enabled) in the geolocation scan cycle, nearby detected BLE beacons and their signal strengths are relayed via LoRaWAN UL to the NS.
- **Beacon Mode**: The sensor broadcasts BLE Tx advertisements so it is discoverable to nearby BLE scanning devices. No geolocation scans of any kind are conducted. The primary use case is for setting up a beacon network for indoor positioning/asset tracking.

In the following subsections, the operational descriptions, report formats, and configurable settings for each mode are explained. The procedure for switching between modes is also explained below.

The sensor supports BLE as specified by Bluetooth 5.2 and uses only the 3 default advertising channels: 37, 38, and 39 [5].

NOTE: The terminology throughout this section is chosen to be clear on whether the described operation relates to tracker mode, beacon mode, or both. When referring to parameters specifically pertaining to tracker mode operation only, the sensor will be referred to as a *tracker*. Similarly, for referring to beacon mode-specific parameters and operation, the device will be referred to as a ***beacon.*** When referring to parameters and operations that are available in both modes, the blanket term *sensor* is used.

6.1 Tracker Mode (BLE Rx)

6.1.1 Operational Description

<u>The default mode of the sensor is tracker mode.</u>

When in tracker mode, geolocation, including BLE, operates in Rx only; the tracker only scans and does not advertise, meaning it is not discoverable by other BLE-capable devices. If BLE scans are defined (enabled) in the geolocation scan cycle, scans will occur periodically according to the rules described in §5.1.1.

During each BLE scan, other nearby advertising BLE devices can be discovered. Each discovered device has its data (MAC address and the RSSI of the advertisement packet) saved by the tracker to then be reported in a LoRaWAN data report UL. This UL is normally reported immediately after the scan concludes but may be delayed due to LoRaWAN duty cycle limitations

The following subsections detail the scanning scheme, data preprocessing options, and device filtering options.

6.1.1.1 Scanning Scheme

A single BLE scan lasts for a configurable *scan duration*.

As illustrated in Figure 6-1, each scan duration is divided into regular *scan intervals*. The beginning of each scan interval marks the beginning of scanning on a different BLE channel frequency. The channels are cycled through in order; during the first scan interval the tracker receives on channel 37, the second on channel 38, the third on channel 39, the fourth on channel 37, and so on. The scan interval is configurable.

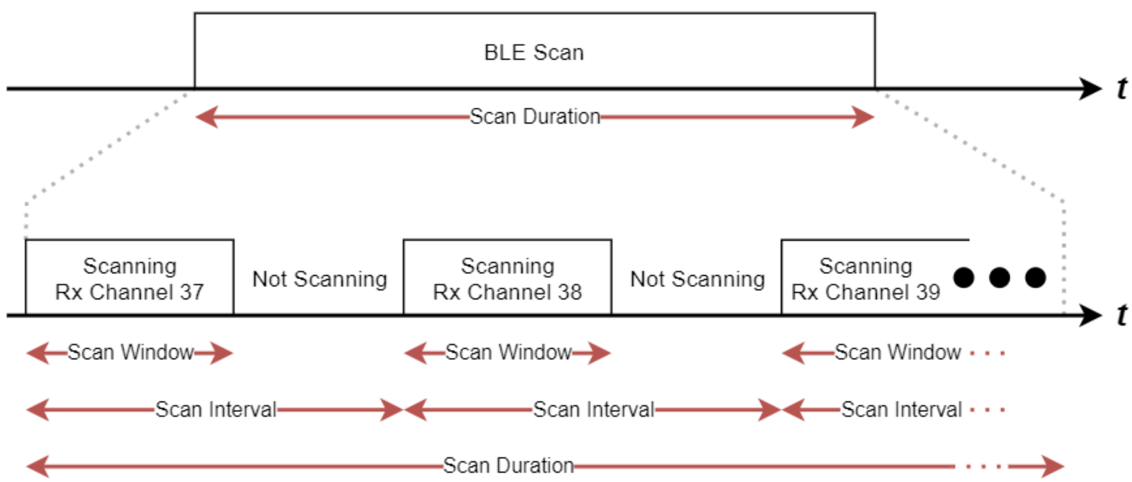


Figure 6-1: The BLE Scan Scheme

Also illustrated in Figure 6-1 actual BLE scanning only occurs during the *scan window* portion of the scan interval. The scan window is configurable, which allows for the *scan duty cycle* to be implemented:

$$\textit{scan duty cycle} = \frac{\textit{scan window}}{\textit{scan interval}} \times 100\%$$

A scan window equal to the scan interval represents a scan duty cycle of 100% (a continuous scan) over each scan duration. This is the default behavior as it maximizes the chance of "discovering" nearby BLE advertisement packets for a given scan duration. Reducing the duty cycle below 100% has the advantage of decreasing power consumption at the expense of possibly missing some beacon signals.

The BLE scan can be disabled entirely and re-enabled at any time in tracker mode. BLE advertising never occurs during tracker mode.

The BLE scan is *passive*. This means the tracker listens to surrounding beacons but does not transmit to them to request additional information.

6.1.1.2 Pre-processing Discovered BLE Device Data (Averaging Mode)

During each scan, if a BLE advertisement is received by the tracker, the BLE device from which that advertisement originated is referred to as a *discovered device*. For each individual advertisement packet received, the SW records:

- The 6-byte *BLE Device MAC address*, BD_{ADDR}, of the advertising device, and
- The 1-byte *Received Signal Strength Indicator* (*RSSI*), in [dBm], of the packet.

The tracker reports up to *N* MAC address + RSSI pairs following each scan, which is configurable via register 0x 50.

During a single scan, it is possible to detect more than one advertisement from a single discovered device if that device is advertising with a period less than the tracker's scan duration. Because of this, the tracker supports the ability to report either the complete, "raw," discovered device data, or apply some pre-processing before reporting. In both cases, a maximum of *N* MAC address + RSSI data pairs are reported:

- **Raw Data:** No pre-processing is done on the packets received during each scan before reporting via UL; the *N* last discovered devices are sent. This means it is possible to have repeated devices in the same UL (one for each received advertisement).
- **Averaging Mode:** The RSSIs from each unique discovered device are averaged over all packets received from that device to get a single value. Then the devices are sorted in order from strongest average RSSI to weakest. The top *N* devices are sent in the UL report. Averaging mode is enabled by default.

6.1.1.3 Filtering Discovered BLE Devices

The tracker supports inclusion filtering of discovered devices based on BD_{ADDR}.

Each 6-byte BD_{ADDR} consists of an *Organizationally Unique Identifier* (*OUI*) comprising the 3 MSBs followed by a *Lower Address Part* (*LAP*) comprising the 3 LSBs in the form:

$$BD_{ADDR} = OUI{:}LAP$$

The *OUI* is unique for a batch of devices; most commonly this means that all devices manufactured by the same company will share the same *OUI*[23]. The *LAP* is unique for each device.

The tracker can filter by single BD_{ADDR} or, more generally, by a range of BD_{ADDR}s if a common *OUI* is shared. This keeps undesired devices out of the OTA report, thus reducing OTA time and saving battery life. An example application is for an indoor BLE beacon network; only the beacon signals are of interest and not those from other devices like smartphones.

[23] TEKTELIC's OUI is 64:7F:DA.

Up to 4 separate filter ranges can be defined and used at the same time. The user must specify the start and end bounds of each range. That is, if a discovered device has a BD_{ADDR} which falls inside the range OUI:LAP_{start} to OUI:LAP_{end} its data is kept. If not, its data is discarded immediately. The range is inclusive, meaning that a BD_{ADDR} equivalent to the start or end bounds is considered in-range. Each range is defined in the following 9-byte format:

$$BD_{ADDR}\ range = \ OUI|LAP_{start}|LAP_{end}$$

The following rules describe the behaviour of the filter ranges and reporting:

1. A range set to all 0s is an *inactive range*. Otherwise, an *active range*. All ranges are inactive by default.
2. All 4 ranges inactive means **basic reporting** is enabled. Following each scan, any and all discovered devices (up to a maximum *N*) are reported. Otherwise, **filtered reporting** is enabled. Basic reporting is the default behaviour.
3. Following any BLE scan, there will be at least 1 report corresponding to each active range. Each report is sent in a separate UL. Even if no devices from a certain range are discovered, an empty list is always sent for that range. See §6.1.2 for more details on reporting.
4. If a range is defined with $LAP_{start} > LAP_{end}$, the range is active but empty. I.e., an empty list is always reported for that range.
5. If an active range is defined with $LAP_{start} = LAP_{end}$, the range has only one BD_{ADDR} in it. This is *single device filtering*.
6. Ranges are allowed to overlap. A BD_{ADDR} that falls into more than one active range will be reported with the message corresponding to the first range it falls into numerically.

NOTE: Averaging/raw modes and basic/filtered reporting are mutually compatible; that is, any combination of the four options is acceptable. Filtering always occurs during the scan, and averaging always occurs after.

6.1.2 UL Report Frame Formats

Discovered BLE devices are reported on ***LoRaWAN port 25***. As described in §6.1.1.3, either basic or filtered reporting can be done.

NOTE 1: 0, 1, or more devices can be reported in a single message, depending on the number of devices available to report and payload size limitation as determined by LoRaWAN regional parameters [4]. For all BLE reporting described below, if the discovered device data cannot fit into one message, more than one UL will be subsequently transmitted to report all *N* devices.

NOTE 2: The scan results are normally reported in a UL immediately after the scan concludes but may be delayed due to duty cycle limitations [4].

6.1.2.1 Basic Reporting

Basic reporting occurs when no filter ranges are active. In this case, following each scan, the data from all discovered devices (up to a maximum *N*) are reported. The UL payload format is shown in Figure 6-2. Basic reporting is the default behaviour.

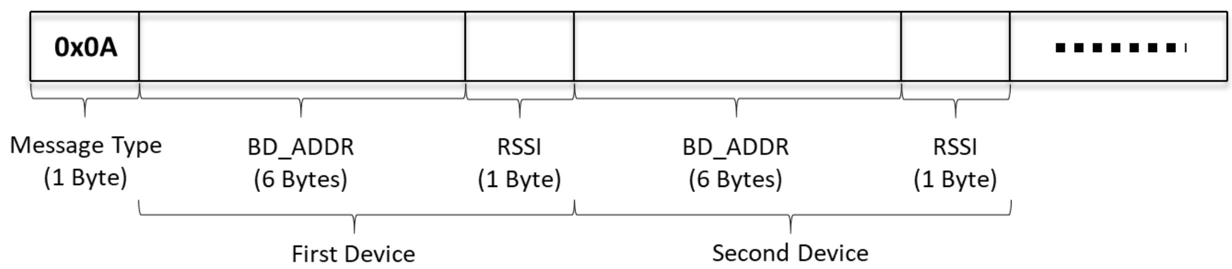


Figure 6-2: The BLE Report UL Payload Format for Basic Reporting

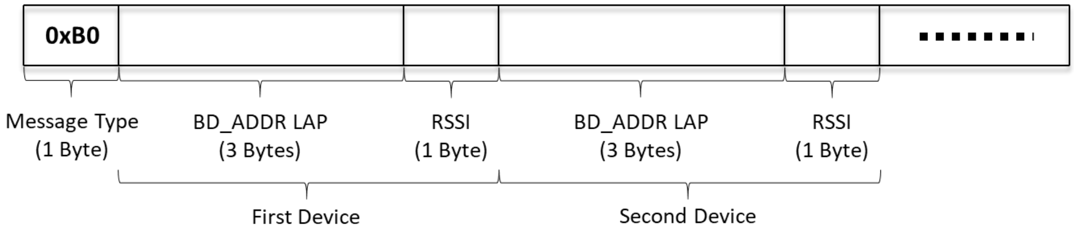
Each payload consists of a 1-byte header (0x 0A) followed by the data from each discovered device. If no devices were discovered during a scan (i.e., the scan failed), an empty list (i.e., only the header) is sent.

The data from each device consists of a 7-byte BD_{ADDR} and RSSI pair, where the BD_{ADDR} is the full 6-byte BLE Device MAC Address and the RSSI is a signed 1-byte number in units of [dBm].

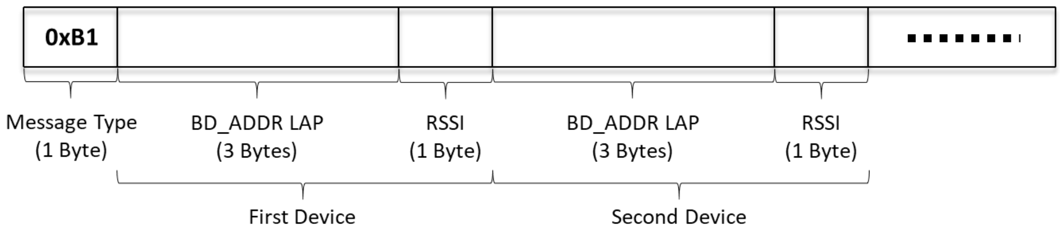
The BD_{ADDR} and RSSI pairs for any other discovered devices are concatenated into the payload. The order of the listed devices depends on whether averaging mode is enabled or disabled (see §6.1.1.2).

6.1.2.2 Filtered Reporting

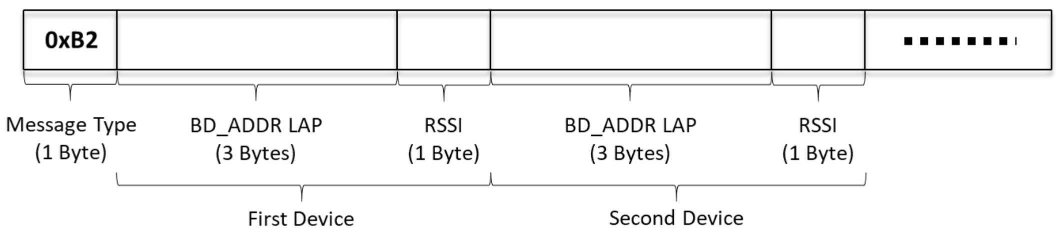
Filtered reporting occurs when one or more filter range is active. In this case, following each scan, only discovered devices (up to a maximum *N*) from specified ranges of favorable BD_{ADDR}s are included in the report. The UL payload formats are shown in Figure 6-3.



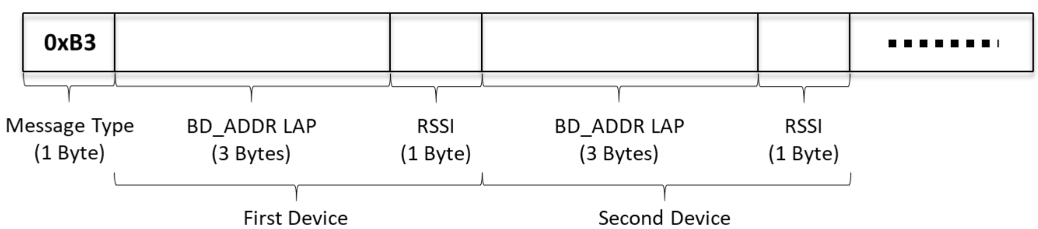
(a) Filter Range 0



(b) Filter Range 1



(c) Filter Range 2



(d) Filter Range 3

Figure 6-3: BLE Report UL Payload Formats for Filtered Reporting

Each payload consists of a 1-byte header followed by the data from each discovered device. The header denotes the filter range corresponding to these devices. Explicitly, BLE reports for ranges 0, 1, 2, and 3 have the headers 0x B0, 0x B1, 0x B2, and 0x B3, respectively. If no devices were discovered during a scan for a particular filter range, an empty list (i.e., only the header) is sent.

The data from each device consists of a 4-byte *LAP* and RSSI pair, where the *LAP* is the 3 LSBs of the BD_{ADDR} and the RSSI is a signed 1-byte number in units of [dBm]. The *OUI* is implicitly known due to the definition of the filter range, so only the *LAP* is necessary for unique identification. See §6.1.1.3 for more details about filter operation.

The *LAP* and RSSI pairs for any other discovered devices are concatenated into the payload. The order of the listed devices depends on whether averaging mode is enabled or disabled (see §6.1.1.2).

There will always be at least 1 report corresponding to each active range following every BLE scan. Each report is sent in a separate UL.

6.1.2.3 Example UL Payloads

- **0x 0A 64 7F DA 00 00 01 C9**
  - Header = 0x 0A → basic BLE data report
  - 0x 64 7F DA 00 00 01 = BD_{ADDR} = 64:7F:DA:00:00:01
  - 0x C9 = RSSI = -55 × 1 dBm = -55 dBm
- **0x B0 12 34 56 C4 AB CD EF 3F**
  - Header = 0x B0 → BLE data report for filter range 0
  - 0x 12 34 56 = device 1 BD_{ADDR} *LAP* = 12:23:56
  - 0x C4 = device 1 RSSI = -60 × 1 dBm = -60 dBm
  - 0x AB CD EF = device 2 BD_{ADDR} *LAP* = AB:CD:EF
  - 0x 3F = device 2 RSSI = -63 × 1 dBm = -63 dBm

6.1.3 Configuration Settings

Table 6-1 shows the list of configuration registers which affect BLE scanning and reporting behaviour. In this table, the bit indexing scheme is as shown in Figure 3-1. To access these registers, a command must be formatted and sent according to the details described in §3.3.2. For configuration settings of the geolocation cycle and GNSS scan parameters, see §5.1.3.

Table 6-1: Tracker Mode Configuration Registers

Address	Value	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 50	BLE Rx Mode	1 B	Access: R/W • Bits 0-6: ***N*** Number of reported devices (1–127) 0: Disables BLE Rx mode • Bit 7: 0/1 = Averaging mode off/on	• Up to 8 reported devices • Averaging mode on **0x 88**	*ble_mode: {* *num_reported_devices: <value>, (unsigned/no unit)* *averaging_mode: <value> (unsigned/no unit)* *}*
0x 51	BLE Scan Duration	2 B	Access: R/W • Bits 0-7: Scan duration [1 s/LSb] Acceptable values: 1, 2, …, 10 0: Invalid and ignored • Bits 8-15: RFU	3 s **0x 00 03**	*ble_scan_duration: {* *periodic: <value>, (unsigned/no unit)* *}*

Address	Value	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 52	BLE Scan Interval	2 B	Access: R/W • Scan interval [1 ms/LSb] • Acceptable values: “Scan Window”, …, 10 000 • Other values: Invalid and ignored	30 ms **0x 00 1E**	*ble_scan_interval: <value>* *(unsigned/sec)*
0x 53	BLE Scan Window	2 B	Access: R/W • Scan window [1 ms/LSb] • Acceptable values: 3, …, “Scan Interval” • Other values: Invalid and ignored	30 ms **0x 00 1E**	*ble_scan_window: <value>* *(unsigned/sec)*
0x 54	Filter Range 0	9 B	Access: R/W • Range 0 for filtered BD_{ADDR}s • $B_0:B_1:B_2:B_3:B_4:B_5$ to $B_0:B_1:B_2:B_6:B_7:B_8$ ▪ OUI = $B_0:B_1:B_2$ ▪ LAP_{start} = $B_3:B_4:B_5$ ▪ LAP_{end} = $B_6:B_7:B_8$	Range inactive **0x 00 00 00 00 00 00 00 00 00**	*filter_range_0: {* *oui: <value>, (unsigned/no unit)* *lap_start: <value>, (unsigned/no unit)* *lap_end: <value> (unsigned/no unit)* *}*
0x 55	Filter Range 1	9 B	Access: R/W • Range 1 for filtered BD_{ADDR}s • $B_0:B_1:B_2:B_3:B_4:B_5$ to $B_0:B_1:B_2:B_6:B_7:B_8$ ▪ OUI = $B_0:B_1:B_2$ ▪ LAP_{start} = $B_3:B_4:B_5$ ▪ LAP_{end} = $B_6:B_7:B_8$	Range inactive **0x 00 00 00 00 00 00 00 00 00**	*filter_range_1: {* *oui: <value>, (unsigned/no unit)* *lap_start: <value>, (unsigned/no unit)* *lap_end: <value> (unsigned/no unit)* *}*
0x 56	Filter Range 2	9 B	Access: R/W • Range 2 for filtered BD_{ADDR}s • $B_0:B_1:B_2:B_3:B_4:B_5$ to $B_0:B_1:B_2:B_6:B_7:B_8$ ▪ OUI = $B_0:B_1:B_2$ ▪ LAP_{start} = $B_3:B_4:B_5$ ▪ LAP_{end} = $B_6:B_7:B_8$	Range inactive **0x 00 00 00 00 00 00 00 00 00**	*filter_range_2: {* *oui: <value>, (unsigned/no unit)* *lap_start: <value>, (unsigned/no unit)* *lap_end: <value> (unsigned/no unit)* *}*
0x 57	Filter Range 3	9 B	Access: R/W • Range 3 for filtered BD_{ADDR}s • $B_0:B_1:B_2:B_3:B_4:B_5$ to $B_0:B_1:B_2:B_6:B_7:B_8$ ▪ OUI = $B_0:B_1:B_2$ ▪ LAP_{start} = $B_3:B_4:B_5$ ▪ LAP_{end} = $B_6:B_7:B_8$	Range inactive **0x 00 00 00 00 00 00 00 00 00**	*filter_range_3: {* *oui: <value>, (unsigned/no unit)* *lap_start: <value>, (unsigned/no unit)* *lap_end: <value> (unsigned/no unit)* *}*

6.1.3.1 Periodic Scanning and Reporting Configuration

Since the BLE scan is one of the supported geolocation technologies, BLE scans occur as part of the geolocation cycle and according to the geolocation strategy described in §5.1.

6.1.3.2 Operational Configuration

The *BLE Rx Mode* register, 0x 50, controls 3 settings:

- *BLE scan enable/disable*: setting bits 0 through 6 to all 0s disables all BLE scanning, even if BLE is defined as one of the geolocation scans. NOTE: this value is ignored if the device is in beacon mode; it is impossible to conduct any scanning while in beacon mode.
- *Number of reported devices, N*: The results of each scan will only include up to *N* discovered devices. If *N* or fewer devices are discovered, all devices are reported. If more than *N* devices are discovered, *N* devices are reported and they are chosen based on whether averaging mode is enabled (see §6.1.1.2).
- *Averaging mode enable/disable*: setting bit 7 to 1 enables averaging mode.

The scan parameters, namely the *BLE scan durations*, *BLE scan interval*, and *BLE scan window*, are all fined by registers 0x 51, 0x 52, and 0x53, respectively.

Registers 0x 54 through 0x 57 define filter ranges 0 through 3, respectively.

6.1.3.3 Example DL Payloads

- Configure the tracker to report the strongest beacon only:
  - DL payload: **0x D0 81**
    - Register 0x 50 with bit 7 set to 1 = 0x D0
    - Number of reported devices = 1, Averaging mode enabled
      - Value bits 0 and 7 set to 1 = 0x 81
- Decrease the scan duty cycle to 50% from default while keeping scan durations the same to save battery life:
  - DL payload: **0x D3 00 0F**
    - Register 0x 53 with bit 7 set to 1 = 0x D3
    - Scan window 15 ms = 0x 00 0F
- Set filters to only report devices with MAC addresses ABCDEF000001 and ABCDEF500000 to ABCDEF999999:
  - DL payload: **0x D4 AB CD EF 00 00 01 00 00 01 D5 AB CD EF 50 00 00 99 99 99**
    - Register 0x 54 with bit 7 set to 1 = 0x D4
    - Filter range 0 = ABCDEF000001 to ABCDEF000001 = 0x AB CD EF 00 00 01 00 00 01
    - Register 0x 55 with bit 7 set to 1 = 0x D5

        - Filter range 1 = ABCDEF500000 to ABCDEF999999 = 0x AB CD EF 50 00 00 99 99 99
- Filter for only TEKTELIC BLE devices:
    - DL payload: **0x D4 64 7F DA 00 00 00 FF FF FF**
        - Register 0x 54 with bit 7 set to 1 = 0x D4
        - Filter range 0 = 647FDA000000 to 647FDAFFFFFF = 0x 64 7F DA 00 00 00 FF FF FF

6.2 Beacon Mode (BLE Tx)

6.2.1 Operational Description

CHICKADEE supports a *beacon mode* function as an alternative to tracker mode. The default mode of the sensor is tracker mode, so it must be switched into beacon mode as described in §6.3.

When in beacon mode, the BLE operates in Tx only, and all geolocation scans are disabled. CHICKADEE sends out periodic BLE *advertisements* which are small packets of data. These packets are discoverable by other CHICKADEEs operating in tracker mode, as well as any other device capable of BLE scanning.

When in beacon mode, the sensor is still LoRaWAN-backhauled. That is, it can still send sensor data in LoRaWAN ULs and be reconfigured through LoRaWAN DLs. Furthermore, all other transducer functions other than geolocation are accessible.

When switching to beacon mode, some of the default configuration settings are changed such that the behaviour reflects the standard beacon use-case[24]. Namely, the accelerometer is disabled, and a periodic battery report is sent once every 24 hours.

The following subsections detail the advertising scheme and packet formats.

6.2.1.1 Advertising Scheme

After a beacon joins the LoRaWAN network, it begins broadcasting BLE advertisements. This continues throughout normal operation as a background process.

The *advertising interval* is the time between the beginnings of consecutive advertisement transmissions as shown in Figure 6-4. It is user-configurable in units of [ms].

[24] The standard beacon is a stationary device mounted on a wall that periodically broadcasts BLE advertisements.

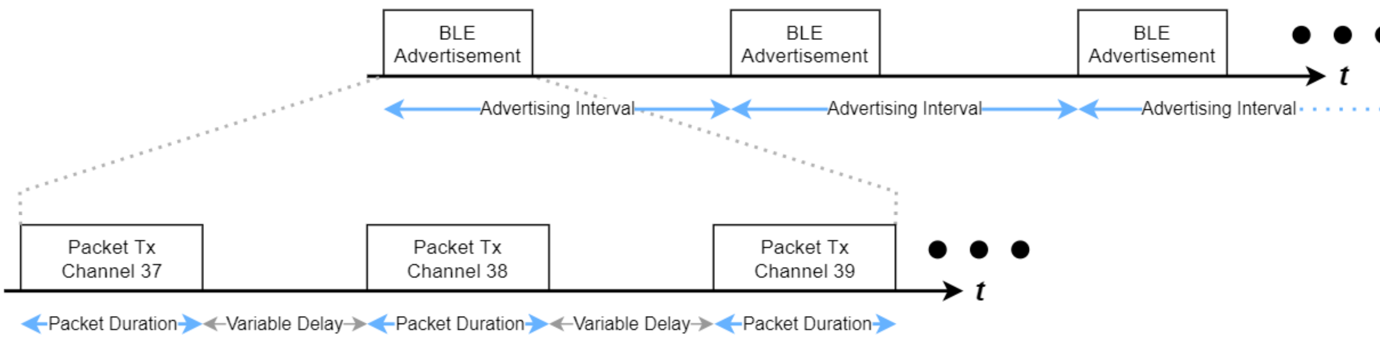


Figure 6-4: The BLE Advertisement Scheme

Figure 6-4 also shows that each single BLE advertisement comprises 3 individual packet transmissions, sent one after another on BLE channels 37, 38, and 39 [5]. This is to maximize the chances of a BLE device scanning on a single channel receiving 1 packet per advertising interval.

Each packet is identical in contents (see §6.2.1.2). Each *packet duration* is approximately 400 µs and is always constant for a given packet format.

Each packet is separated by a delay of between 0 and 6 ms. The BLE module adds some random offset to the start of each packet transmission to mitigate synchronization issues, so the actual interval between transmissions will vary. The combined offsets translate to a total advertisement duration of between 2 and 8 ms and total error in the advertising interval of ±10 ms.

In addition to the advertising interval, the *advertisement Tx power* level is a configurable operational parameter.

The BLE advertisement and LoRa radio transmission are mutually exclusive and never overlap. If any reporting becomes due, the BLE advertisements are paused while the LoRa activity occurs.

NOTE: The advertising interval is independent from the application tick settings. The sensor data LoRaWAN reporting intervals and BLE advertising interval are independently configurable.

6.2.1.2 Advertisement Packet Formats

The BLE advertising packet formatting supports three major BLE standards: iBeacon, Eddystone UID, and Eddystone TLM. By default, only iBeacon is enabled. Figure 6-5 shows the frame breakdown of each of these packet formats.

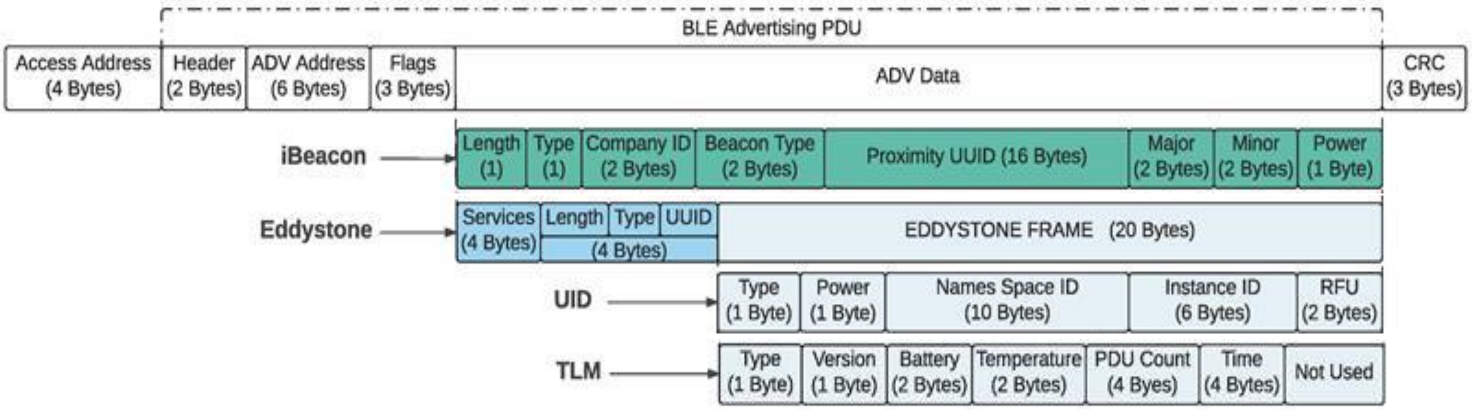


Figure 6-5: Supported Standard BLE Beacon Advertisement Packet Formats

None of the frame contents are user configurable. The important frames that relate directly to device operation are described as follows:

- **ADV Address:** This is the 6-byte BLE Device MAC Address, BD_{ADDR}, and is included in all packet format types.
- **iBeacon <Proximity UUID>**: A 16-byte unique identifier. This field is populated by the beacon's LoRaWAN DevEUI twice. For example, if the DevEUI is 647FDA0000001234, then the iBeacon Proximity UUID would be 647FDA0000001234-647FDA0000001234.
- **Eddystone UID <Namespace ID**>: A 10-byte unique identifier. This field is populated by the beacon's LoRaWAN DevEUI, followed by 2-bytes of 0s. For example, if the DevEUI is 647FDA0000001234, then the Eddystone UID Namespace ID would be 647FDA00000012340000.
- **Eddystone TLM <Battery>:** This field is populated with battery report data. The data type is always remaining battery lifetime. This is the same number that gets reported OTA in a LoRaWAN battery report UL, in units of 1 day/LSb. For example, if the remaining battery lifetime is 1029 days, then <Battery> would be 0x 04 05.
- **Eddystone TLM <Temperature>:** This field is populated with MCU temperature data. This is the same number that gets reported OTA in a LoRaWAN UL, except represented in 8.8 fixed-point notation (standard for Eddystone encoding/decoding). For example, if the MCU temperature was measured to be 23.8°C, then <Temperature> would be 0x 17 CD.
- **Eddystone TLM <PDU Count>:** A running counter that increments every time the beacon emits a new advertisement frame (of any type). This counter is reset to 0 upon hard and soft resets.
- **Eddystone TLM <Time>:** A counter that represents the time since the beacon is powered on or rebooted. This is represented in 0.1 s/LSb. This counter is reset to 0 upon hard and soft resets.

The descriptions of the purposes of the other frames are unrelated to beacon function and outside the scope of this document. For complete descriptions of the frames, refer to the BLE 5.3 Core Specification [5].

Any combination of the 3 packet formats can be enabled at once. If more than 1 format is enabled, the packets are interleaved with each advertising interval. In other words, the packet format changes with each advertisement and cycles through all enabled options.

For example, consider the case with all 3 formats enabled and an advertising interval of 100ms. In this case, at 100ms, 3 iBeacon packets are transmitted, one on each channel. At 200ms, 3 Eddystone UID packets are transmitted. At 300ms, 3 Eddystone TLM packets are transmitted. At 400ms, 3 iBeacon packets are transmitted, etc.

6.2.2 Configuration Settings

Table 6-2 shows the list of configuration registers which affect BLE Tx behaviour. In this table, the bit indexing scheme is as shown in Figure 3-1. To access these registers, a command must be formatted and sent according to the details described in §3.3.2.

Table 6-2: BLE Advertising Configuration

Address	Value	Size	Description and Options	Default Value[25]	JSON Variable (Type/Unit)
0x 58	BLE Advertising Enable / Disable	1 B	Access: R/W • Bits 7-1: Ignored • Bit 0: 0/1 = Advertising disabled/enabled	Advertising disabled **0x 00**	*advertising_enabled: <value> (unsigned/no unit)*
0x 59	BLE Advertising Interval	2 B	Access: R/W • Advertising interval [1 ms/LSb] • Acceptable values: 100 ms – 10240 ms • Other values: Invalid and ignored	100 ms **0x 00 64**	*min_advertising_interval: <value> (unsigned/ms)*

[25] The default values in this (and all other tables like it throughout this document) are the sensor default. Since the default sensor mode is tracker mode, all default values represent tracker mode defaults. When the sensor is switched to beacon mode, some default values change automatically. For more information, see §6.3. For a summary of all register default values in both tracker and beacon mode, see Table in Appendix 2 .

Address	Value	Size	Description and Options	Default Value[25]	JSON Variable (Type/Unit)
0x 5B	BLE Tx Advertising Power	1 B	Access: R/W • BLE Tx Power [dBm] ▪ 0x 00 = 0 dBm ▪ 0x 01 = -0.85 dBm ▪ 0x 02 = -1.8 dBm ▪ 0x 03 = -3.15 dBm ▪ 0x 04 = -4 dBm ▪ 0x 05 = -4.95 dBm ▪ 0x 06 = -5.9 dBm ▪ 0x 07 = -6.9 dBm ▪ 0x 08 = -7.8 dBm ▪ 0x 09 = -8.85 dBm ▪ 0x 0A = -9.9 dBm ▪ 0x 0B = -12.05 dBm ▪ 0x 0C = -14.1 dBm ▪ 0x 0D = -16.5 dBm ▪ 0x 0E = -20.85 dBm ▪ 0x 0F = -40 dBm • Other values: Invalid and ignored	0 dBm **0x 00**	*tx_advertising_power: <value> (unsigned/no unit)*
0x 5C	BLE Advertisement Packet Format	1 B	Access: R/W • Bit 0: 0/1 = iBeacon advertising disabled/enabled • Bit 1: 0/1 = Eddystone UID advertising disabled/enabled • Bit 2: 0/1 = Eddystone TLM advertising disabled/enabled • Bits 3-7: RFU • All set to 0: Invalid and ignored	• iBeacon enabled • Eddystone UID disabled • Eddystone TLM disabled **0x 01**	*advertising_packet_format: {* *ibeacon: <value>, (unsigned/no unit)* *eddystone_uid: <value>, (unsigned/no unit)* *eddystone_tlm: <value> (unsigned/no unit)* *}*
0x 5F	BLE MAC Address	6 B	Access: RO • The 6-Byte BLE Device MAC address, BD_{ADDR}, of the sensor.	Unique for every sensor	*mac_address: <value> (unsigned/no unit)*

6.2.2.1 *Operational Configuration*

The *BLE Advertising Enable/Disable* register, 0x 58, allows advertising to start and stop as needed in beacon mode. By default, the sensor is in tracker mode, so advertising is disabled. When switched to beacon mode, this register value gets changed to enable advertising. In tracker mode, the value of this register is ignored; it is impossible to transmit BLE advertisements while in tracker mode.

Registers 0x 59 and 0x 5B determine the advertising interval and the advertisement Tx power, respectively. The higher these values, the more power the sensor consumes while in beacon mode. These values should be configured with respect to balancing the desired battery lifetime and beacon detectability for each particular use-case.

The packet format(s) are enabled or disabled by the value of register 0x 5C.

6.2.2.2 BLE Device MAC Address

Any device capable of BLE has a unique 6-Byte MAC address identifier. This is the ID that is contained in the BLE advertisement packets and by which discovered devices are filtered (see §6.1.2.2).

Register 0x 5E contains the MAC address of that device and it has read-only access. This is the same MAC address that is printed on the device label.

When the device is switched into Beacon mode (described in §6.3**Error! Reference source not found.**), upon rejoining the LoRaWAN network, the first UL with an application frame payload will contain the MAC address of the device. For example, if the device's MAC address is ABCDEF012345, the UL payload is **0x 5F AB CD EF 01 23 45** and is sent on **LoRaWAN port 100** as if in response to a DL request to read register 0x 5F (see §3.2.3).

6.2.2.3 Example DL Payloads

- Change the Beacon's BLE advertisement power to -3.15 dBm:
  - DL payload: **0x DB 03**
    - Register 0x 5B with bit 7 set to 1 = 0x DB
    - Power setpoint 3 = 0x 03
- Change the advertising interval to 5 s:
  - DL payload: **0x D9 13 88**
    - Register 0x 59 with bit 7 set to 1 = 0x D9
    - Advertising interval = 5000 ms = 0x 13 88
- Read MAC address and change the advertising packet format to Eddystone TLM:
  - DL payload: **0x 5F DC 04**
    - Register 0x 5F with bit 7 set to 0 = 0x 5F
    - Register 0x 5C with bit 7 set to 1 = 0x DC
    - Value bit 2 set to 1 = 0x 04

6.3 Toggling Tracker Mode ↔ Beacon Mode

6.3.1 Toggling Procedure and Commands

The device can operate in 1 of 2 modes at a time:

- ***Tracker mode***: BLE Rx only.
- ***Beacon mode***: BLE Tx only.

The mode is defined by register 0x 0A. Switching between modes is done by sending a DL command to reconfigure the register according to the details described in §3.3.2. Table 6-3 shows the details and values for register 0x 0A. In this table, the bit indexing scheme is as shown in Figure 3-1.

Table 6-3: Tracker/Beacon Mode Configuration Register

Address	Name	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 0A	Tracker/Beacon Mode	1 B	Access: R/W • 0x 00 = Tracker Mode • 0x 01 = Beacon Mode	Tracker Mode **0x 00**	*tracker_beacon_mode: <value>* *(unsigned/no unit)*

The write command to reconfigure register 0x 0A doubles as an executable command. That is, when a DL containing a command block to reconfigure register 0x 0A is received, a set of actions occur:

1. Configuration DL received containing a mode switch command. The value of register 0x 0A is overwritten with the new value.
2. Sensor resets.
3. Sensor enters JOIN mode, attempting to rejoin the LoRaWAN network.
4. Once rejoined, the sensor operates in the mode specified by the DL in step 1.

The explicit commands and procedures are as follows:

- **Switch to Beacon Mode:**
  - DL payload **0x 8A 01**.
  - Sensor behaviour upon rejoin: the first LoRaWAN UL with an application frame payload will be sent on ***LoRaWAN port 100*** and contain the MAC address as described in §6.2.2.2.
- **Switch to Tracker Mode**:
  - DL payload **0x 8A 00**.
  - Sensor behaviour upon rejoin: a geolocation cycle is conducted.

NOTE: The current mode (current value of register 0x 0A) does not impact the behaviour upon receiving a mode switch command. E.g., if a command to switch to tracker mode is received when already in tracker mode, the sensor will still reset and rejoin. Consequently, any other configuration and control blocks included in the same payload as a mode switch command block will not be applied.

6.3.2 Differences Between Modes

Tracker and beacon modes differ only by the values of certain configuration registers.

The default mode is tracker mode, so default sensor configuration settings is equivalent to default tracker mode settings. When switching to beacon mode, a different set of *default beacon mode* configuration values are loaded and used by the sensor after it resets and rejoins the LoRaWAN network.

The only default register values that differ between modes are listed in Table 6-4. The default values of all other registers not listed in Table 6-4 are not affected by switching between Tracker and Beacon modes; that is, all other registers do not impact specific Tracker or Beacon mode operation and can be configured independently, regardless of the current mode.

Table 6-4: Default Register Values for Tracker/Beacon Mode

Name	Register Address	Default Value, Tracker Mode (Factory Default)	Default Value, Beacon Mode
LoRaMAC DR and Tx Power	0x 12	0x 03 00	0x 00 00
Ticks per Geolocation Update in STILL State	0x 22	0x 00 3C	0x 00 00
Ticks per Geolocation Update in MOBILE State	0x 23	0x 00 0A	0x 00 00
Ticks per Geolocation Update in EMERGENCY State	0x 24	0x 00 04	0x 00 00
Accelerometer Mode	0x 40	0x 87	0x 07
Acceleration Event Value to Tx	0x 46	0x 03	0x 01
Advertising Enable / Disable	0x 58	0x 00	0x 01

For a complete list of both default tracker mode and default beacon mode configuration settings, see Table A2-2 in Appendix 2 .

7 Accelerometer Operation

CHICKADEE is equipped with an accelerometer that can measure the direction and magnitude of acceleration on up to 3 individual axes: ±X, ±Y, and ±Z.

The accelerometer is enabled by default. When enabled, it operates constantly in the background during normal operation, making measurements at a configurable *sample rate*.

The accelerometer measurement sampling can be used for 3 main sensor functions:

- **Orientation Detection:** the accelerations on each axis can be reported periodically.
- **Motion Detection Alarms:** if the acceleration samples meet certain threshold criteria, “motion detected” and “motion clear” alarm reports can be generated.
- **Accelerometer Assist:** if acceleration samples meet certain threshold criteria, the sensor can speed up or slow down geolocation updates, depending on whether motion is detected or cleared.

<u>By default, orientation reporting is disabled, but motion detection alarms and accelerometer assist are enabled in tracker mode.</u> The accelerometer is disabled entirely by default in beacon mode.

The general behaviour and configuration, as well as the descriptions of the 3 sensor accelerometer functions above are detailed in the following subsections.

7.1 General Sampling Behaviour

7.1.1 Operational Description

Regardless of which sensor accelerometer function is being used, the basic measurement scheme is the same. A single accelerometer measurement sample is comprised of the direction and magnitude of acceleration on up to 3 individual axes: ±X, ±Y, and ±Z.

The acceleration magnitude is measured in units of *acceleration due to gravity*, *g*, where 1 *g* is equivalent to the acceleration experienced by a body at rest on earth’s surface: 9.810m/s^2. By definition, measuring acceleration means detecting changes in movement.

The accelerometer is enabled by default. When enabled, it operates constantly in the background during normal operation, making measurements at a configurable *sample rate*. As with any physical sampling, any real acceleration value must be sustained longer than the sample period to be accurately measured. Quicker sample rates have a shorter period and can therefore resolve shorter physical acceleration events. However, sampling the transducer at a quicker rate increases the power consumption, impacting the battery life.

The *measurement range* is configurable and defines the full dynamic range of accelerations that can be monitored on any enabled axis. Since the accelerometer output is always an 8-bit signed number, a larger measurement range means less precision (i.e., a larger *g* unit per LSb). Explicitly, the supported measurement ranges of ±2 *g*, ±4 *g*, ±8 *g*, ±16 *g* correspond to typical output precisions of 16 m*g*, 32 m*g*, 64 m*g*, 192 m*g*, respectively[26]. If the physical acceleration magnitude is outside the current measurement range at the time of sampling, it will not be registered.

7.1.2 Configuration Settings

Table 7-5 shows the list of configuration registers which control general accelerometer behaviour. In this table, the bit indexing scheme is as shown in Figure 3-1. To access these registers, a command must be formatted and sent according to the details described in §3.3.2.

Table 7-1: General Accelerometer Configuration Registers

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x 40	Accelerometer Mode	1 B	Access: R/W • Bit 0: 0/1 = X-axis disabled/enabled • Bit 1: 0/1 = Y-axis disabled/enabled • Bit 2: 0/1 = Z-axis disabled/enabled • Bits 3-6: Ignored • Bit 7: 0/1 = Accelerometer off/on	• X-axis enabled • Y-axis enabled • Z-axis enabled • **0x 87**	*accel_mode: {* *xaxis_enabled: <value>, (unsigned/no unit)* *yaxis_enabled: <value>, (unsigned/no unit)* *zaxis_enabled: <value>, (unsigned/no unit)* *power_on: <value> (unsigned/no unit)* *}*
0x 41	Accelerometer Sensitivity	1 B	Access: R/W • Bits 0-2: Sample Rate: 1/2/3/4/5/6/7 = 1/10/25/50/100/200/400 Hz 0: Invalid and ignored • Bits 4-5: Measurement Range: 0/1/2/3 = ±2/±4/±8/±16 *g* • Bits 3, 6, 7: Ignored	• Sample Rate = 10 Hz • Measurement Range = ±8 *g* **0x 22**	*accel_sensitivity: {* *sample_rate: <value>, (unsigned/Hz)* *measurement_range: <value> (unsigned/g)* *}*

[26] The magnitudes are always reported by the sensor with 0.001 *g* = 1 m*g* resolution, regardless of attainable precision given the current measurement range.

7.1.2.1 Operational Configuration

The *sample rate* and *measurement range* are both defined by the *accelerometer sensitivity* register, 0x 41. The options for both parameters are listed in Table 7-1.

These settings apply in general for all 3 sensor accelerometer functions (orientation detection, motion alarms, and accelerometer assist).

7.1.2.2 Example DL Payloads

- Set sample rate to 400 Hz and measurement range to 0:
  - DL payload: **0x C1 07**
    - Register 0x 41 with bit 7 set to 1 = 0x C1
    - Sample rate option 7, measurement range option 0 = 0x 07

7.2 Orientation Detection

7.2.1 Operational Description

The sensor orientation is expressed quantitatively as an *acceleration vector,* $\vec{a}$:

$$\vec{a} = (x, y, z)$$

Where *x*, *y*, and *z* represent the measured acceleration components on each of the 3 axes X, Y, and Z, respectively. These components can be positive or negative, depending on the direction of net acceleration on each axis.

For a stationary sensor, the total acceleration *magnitude*[27] should be approximately 1 *g*; the only net acceleration experienced by a non-moving body is gravity. Therefore, the vector components can be used to determine the direction of gravity and therefore the sensor orientation.

The sensor can be configured to send an accelerometer vector report periodically. By default, vector reports are disabled.

7.2.2 UL Report Frame Formats

Accelerometer vector reports are sent on ***LoRaWAN port 10*** and have the frame format as shown in Figure 3-2. The specific details for the accelerometer vector report frame format are listed in Table 7-2. For the general description of sensor data report formats and behaviour, see §3.2.1.

[27] Acceleration magnitude is defined as $a = \|\vec{a}\| = \sqrt{x^2 + y^2 + z^2}$

Table 7-2: Accelerometer Vector Report UL Frame Format

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Acceleration Vector	0x 00	0x 71	6 B	Acceleration	• [1 mg/LSb] (signed) • Bits 32-47: X-axis acceleration • Bits 16-31: Y-axis acceleration • Bits 0-15: Z-axis acceleration	*acceleration_vector { xaxis: <value>, (signed/g) yaxis: <value>, (signed/g) zaxis: <value> (signed/g) }*

7.2.2.1 Example UL Payloads

- **0x 00 71 00 00 00 00 03 E8**
  - Channel ID = 0x 03, Type ID = 0x 72 → acceleration vector data report
  - 0x 00 00 = 0 × 1 mg = 0.000 g in X-direction
  - 0x 00 00 = 0 × 1 mg = 0.000 g in Y-direction
  - 0x 03 E8 = 1000 × 1 mg = 1.000 g in Z-direction
- **0x 00 71 00 00 FB 50 00 00**
  - Channel ID = 0x 03, Type ID = 0x 72 → acceleration vector data report
  - 0x 00 00 = 0 × 1 mg = 0.000 g in X-direction
  - 0x FB 50 = -1200 × 1 mg = -1.200 g in Y-direction
  - 0x 00 00 = 0 × 1 mg = 0.000 g in Z-direction

7.2.3 Configuration Settings

Table 7-3 shows the list of configuration registers which affect accelerometer vector reporting behaviour. In addition to these registers, the configuration parameters listed in Table 7-1 also affect general accelerometer behaviour. In this table, the bit indexing scheme is as shown in Figure 3-1. To access these registers, a command must be formatted and sent according to the details described in §3.3.2.

Table 7-3: Accelerometer Vector Report Configuration Registers

Address	Name	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 20	Seconds per Core Tick	4 B	Access R/W • Tick value for periodic events • Acceptable values: 15, 16, 17, …, 86400 • Other values: Invalid and ignored	60 s = 1 min **0x 00 00 00 3C**	*seconds_per_core_tick: <value> (unsigned/s)*

Address	Name	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 25	Ticks per Accelerometer	2 B	Access R/W • Ticks between accelerometer vector reports • Acceptable values: 0, 1, 2, …, 65535 • 0: disables periodic accelerometer vector reports	Periodic reporting disabled **0x 00 00**	*ticks_per_accelerometer: <value>* *(unsigned/no unit)*

7.2.3.1 Periodic Reporting Configuration

The accelerometer vector reporting period can be configured using registers 0x 20 and 0x 25 according to the equation described in §4.2.2. That is:

$$\textbf{\textit{Accelerometer Reporting Period}} = \textbf{\textit{Seconds per Core Tick}} \times \textbf{\textit{Ticks per Accelerometer}}$$

Setting the accelerometer reporting period to 0 disables periodic reporting of vector orientation data.

7.2.3.2 Example DL Payload

- Schedule a vector report every 48 hours:
  - DL payload: **0x A0 00 00 0E 10 A4 00 30**
    - Register 0x 20 with bit 7 set to 1 = 0x A0
    - 3600 s/core tick = 0x 00 00 0E 10
    - Register 0x 24 with bit 7 set to 1 = 0x A4
    - Report every 48 ticks = 0x 00 30

7.3 Motion Detection Alarms

7.3.1 Operational Description

The accelerometer measurements can be used to generate event-based reports when:

- New motion is detected. This is called an ***acceleration event***.
- The motion has ended. This is called an ***acceleration clear***.

<u>**Motion Detected:**</u>

To determine when motion is detected, ***acceleration triggers*** are used. An acceleration trigger is registered when a certain number of acceleration samples are collected that exceed the trigger threshold, within a certain period after the first above-threshold sample is detected.

Explicitly, with default configuration settings, as soon as the acceleration magnitude on any axis is measured to be greater than 2 *g* (register 0x 44, *Acceleration Trigger Threshold*) 1 time (register

0x 42, *Acceleration Trigger Threshold Count*) in less than 10 seconds (register 0x 43, *Acceleration Trigger Threshold Period*), an acceleration trigger is registered.

The first trigger to occur after the last motion was cleared is interpreted as new motion detected. When this occurs, an acceleration event is registered and a “motion detected” alarm report is sent in a LoRaWAN UL if alarms are enabled.

Motion Cleared:

To determine when the motion has ended, the configurable *Acceleration Event Grace Period* timer (register 0x 45) is employed. With each newly registered accelerometer trigger, the grace period timer is reset and begins counting down. If the timer elapses without any further registered triggers, the motion is considered ended; an accelerometer clear is registered and a “motion cleared” alarm report is sent in a LoRaWAN UL if alarms are enabled.

No additional “motion detected” alarms are reported before the first acceleration clear is registered, even if more acceleration triggers are registered.

Alarm reporting is enabled by default in tracker mode but can be disabled without turning the accelerometer off. The accelerometer is off by default in beacon mode.

All alarm reporting is event-based; no periodic reporting behaviour is supported.

An example sequence of detected motion and generated alarm ULs is illustrated in Figure 7-1.

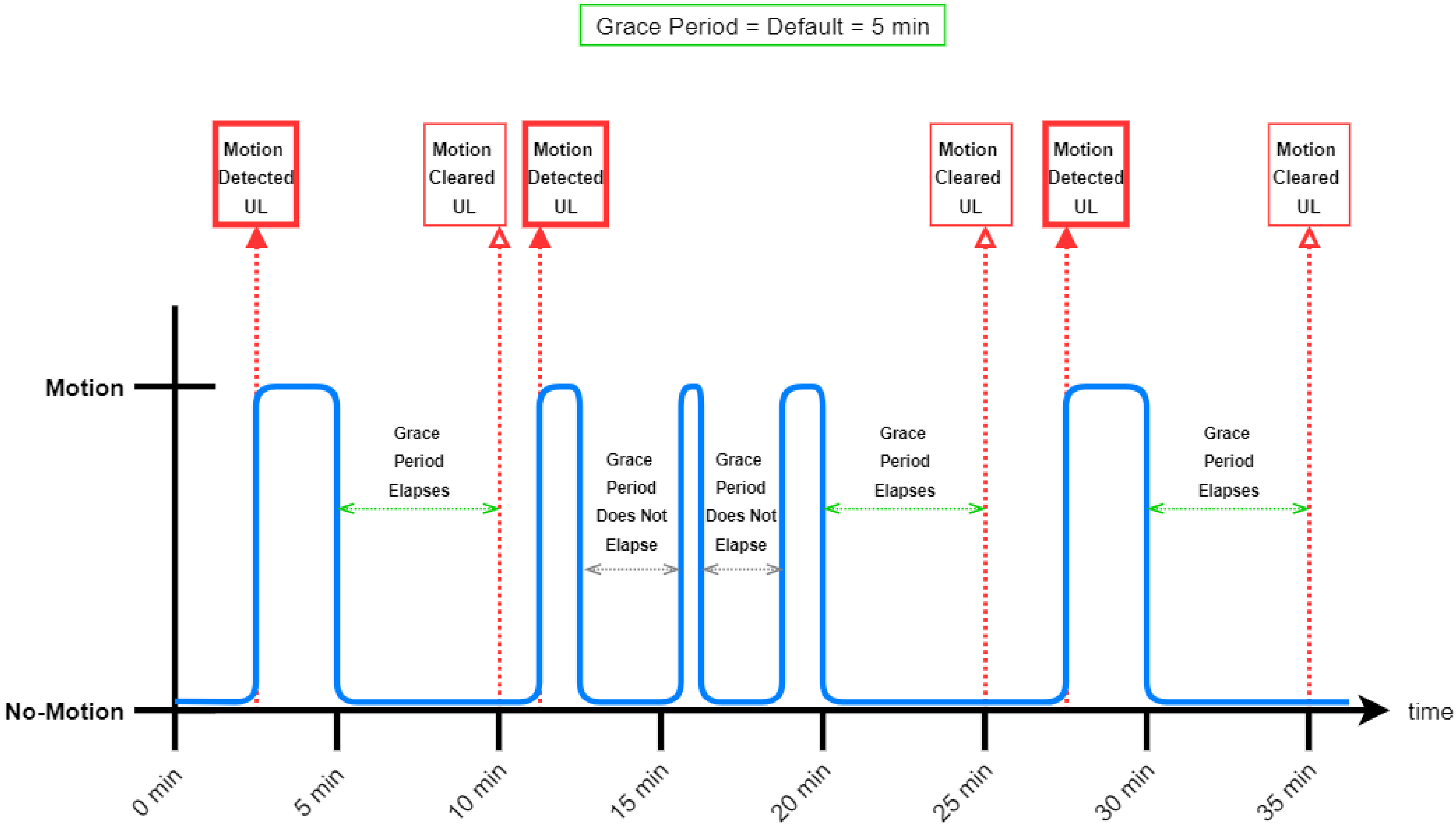


Figure 7-1: Example Sequence of Accelerometer Events and UL Reports

7.3.2 UL Report Frame Formats

Accelerometer alarm reports are sent on ***LoRaWAN port 10*** and have the frame format as shown in Figure 3-2. The specific details for the alarm report frame format are listed in Table 7-4. For the general description of sensor data report formats and behaviour, see §3.2.1.

Table 7-4: Accelerometer Vector Report UL Frame Format

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Acceleration Alarm Status	0x 00	0x 00	1 B	Digital Input	• 0x 00 = Alarm inactive (motion no longer detected) • 0x FF = Alarm active (motion detected)	*acceleration_alarm (unsigned/no unit)*

7.3.2.1 Example UL Payloads

- **0x 00 07 00**
  - Channel ID = 0x 00, Type ID = 0x 00 → acceleration alarm status report
  - 0x FF = Motion Detected

- **0x 00 00 00**
  - Channel ID = 0x 00, Type ID = 0x 00 → acceleration alarm status report
  - 0x 00 = Motion Cleared

7.3.3 Configuration Settings

Table 7-5 shows the list of configuration registers which affect accelerometer alarm reporting behaviour. In addition to these registers, the configuration parameters listed in Table 7-1 also affect general accelerometer behaviour. In these tables the bit indexing scheme is as shown in Figure 3-1. To access these registers, a command must be formatted and sent according to the details described in §3.3.2.

Table 7-5: Accelerometer Motion Detection Alarm Configuration Registers

Address	Value	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 42	Acceleration Trigger Threshold Count	2 B	Access: R/W • Number of above-threshold acceleration samples before an acceleration trigger is registered • Acceptable values: ≥ 1 • 0: Invalid and ignored	1 trigger **0x 00 01**	*accl_trigger_threshold_count: <value> (unsigned/no unit)*
0x 43	Acceleration Trigger Threshold Period	2 B	Access: R/W • Period over which acceleration samples are counted for trigger detection [1s/LSb] • Acceptable values: ≥ 5 • 0-4: Invalid and ignored	10 seconds **0x 00 0A**	*accl_trigger_threshold_period: <value> (unsigned/s)*
0x 44	Acceleration Trigger Threshold	2 B	Access: R/W • Acceleration magnitude threshold for acceleration trigger [1 mg/LSb]	250 *mg* **0x 00 FA**	*accl_trigger_threshold: <value> (unsigned/mg)*
0x 45	Acceleration Event Grace Period	2 B	Access: R/W • Time to pass after the last accelerometer trigger before the event is cleared [1s/LSb] • Acceptable values: ≥ 15 • 0-14: Invalid and ignored	5 min **0x 01 2C**	*accl_event_grace_period: <value> (unsigned/s)*

Address	Value	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 46	Acceleration Event Value to Tx	1 B	Access: R/W • Bit 0: 0/1 = Acceleration alarm UL report disabled/enabled • Bit 1: 0/1 = Accelerometer Assist for geolocation disabled/enabled • Bits 2-7: Ignored	• Acceleration alarm report UL enabled • Accelerometer Assist enabled **0x 03**	*accl_tx: {* *accl_alarms: <value>, (unsigned/no unit)* *accl_assist: <value>, (unsigned/no unit)* *}*

7.3.3.1 Operational Configuration

The *Acceleration Event Value to Tx* register, 0x 46, controls whether motion detection alarm reporting is enabled or disabled. Setting bit 0 to 1 enables alarm reporting. This register also controls whether accelerometer behaviour should result in a change to how frequently geolocation cycles are done through enabling/disabling the *Accelerometer Assist* feature. See §7.4 for a description of this feature.

The threshold criteria for accelerometer triggers, events, and clears are defined by the *Acceleration Trigger Threshold Count*, *Acceleration Trigger Threshold Period*, *Acceleration Trigger Threshold*, and *Acceleration Event Grace Period* registers. These are registers 0x 42, 0x 43, 0x 44, and 0x 45, respectively.

7.3.3.2 Example DL Payloads

- Change threshold value to 800 m*g*:
  - DL payload: 0x **C4 03 20**
    - Register 0x 44 with bit 7 set to 1 = 0x C4
    - 800 m*g* = 0x 03 20
- Read *Acceleration Event Value to Tx*:
  - DL payload: **0x 46**
    - Register 0x 46 with bit 7 set to 0 = 0x 46

7.4 Accelerometer Assist for Geolocation

7.4.1 Operational Description

In addition to motion detection alarm reporting as described in §7.3, *accelerometer events* and *acceleration clears* can trigger the transitions between geolocation update periods. That is, when the ***Accelerometer Assist*** function is enabled,

- When new motion is detected:
    - A new geolocation cycle begins immediately.
    - New geolocation cycles occur periodically according to the MOBILE geolocation update period.
- When the motion has ended:
    - A new geolocation cycle begins immediately.
    - New geolocation cycles occur periodically according to the STILL geolocation update period.

The geolocation update periods are both configurable (see §5.1.3.1). A single scan will always occur upon state transitions even if the update period for that state is set to 0 (i.e., geolocation updating is disabled for that state).

For location tracking, Accelerometer Assisted geolocation scans help to get location updates at appropriate rates: faster when moving and slower when still. Accelerometer Assist also helps to update the location at 2 critical times; when objects leave old locations and settle in new ones.

Accelerometer Assist is triggered under the same configurable conditions as acceleration alarm reporting. Namely, by *accelerometer event* and *acceleration clear* registrations according to the *Acceleration Trigger Threshold*, *Acceleration Trigger Threshold Count*, and *Acceleration Trigger Threshold Period* settings. See §7.3.1 for details on how these are registered.

<u>Accelerometer Assist is enabled by default in tracker mode and permanently disabled in beacon mode.</u>

When accelerometer assist is disabled, or if it is enabled and the accelerometer is off, CHICKADEE will consider itself STILL at all times.

7.4.2 Configuration Settings

Table 7-6 shows the list of configuration registers which affect Accelerometer Assist behaviour. In addition to these registers, the configuration parameters listed in Table 7-1 also affect general accelerometer behaviour. In these tables the bit indexing scheme is as shown in Figure 3-1. To access these registers, a command must be formatted and sent according to the details described in §3.3.2.

Table 7-6: Accelerometer Assist Configuration Registers

Address	Value	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 42	Acceleration Trigger Threshold Count	2 B	Access: R/W • Number of above-threshold acceleration samples before an acceleration trigger is registered • Acceptable values: ≥ 1 • 0: Invalid and ignored	1 trigger **0x 00 01**	*accl_trigger_threshold_count: <value> (unsigned/no unit)*
0x 43	Acceleration Trigger Threshold Period	2 B	Access: R/W • Period over which acceleration samples are counted for trigger detection [1s/LSb] • Acceptable values: ≥ 5 • 0-4: Invalid and ignored	10 seconds **0x 00 0A**	*accl_trigger_threshold_period: <value> (unsigned/s)*
0x 44	Acceleration Trigger Threshold	2 B	Access: R/W • Acceleration magnitude threshold for acceleration trigger [1 m*g*/LSb]	250 *mg* **0x 00 FA**	*accl_trigger_threshold: <value> (unsigned/mg)*
0x 45	Acceleration Event Grace Period	2 B	Access: R/W • Time to pass after the last accelerometer trigger before the event is cleared [1s/LSb] • Acceptable values: ≥ 15 • 0-14: Invalid and ignored	5 min **0x 01 2C**	*accl_event_grace_period: <value> (unsigned/s)*
0x 46	Acceleration Event Value to Tx	1 B	Access: R/W • Bit 0: 0/1 = Acceleration alarm UL report disabled/enabled • Bit 1: 0/1 = Accelerometer Assist for geolocation disabled/enabled • Bits 2-7: RFU	• Acceleration alarm report UL enabled • Accelerometer Assist enabled **0x 03**	*accl_tx: { accl_alarms: <value>, (unsigned/no unit) accl_assist_ble: <value>, (unsigned/no unit) }*

7.4.2.1 Operational Configuration

The *Acceleration Event Value to Tx* register, 0x 46, controls whether Accelerometer Assist is enabled or disabled. Setting bit 1 to 1 enables Accelerometer Assist. This register also controls whether accelerometer behaviour should result in motion detection reports through the alarm reporting feature. See §7.3 for a description of this feature.

The threshold criteria for accelerometer triggers, events, and clears are defined by the *Acceleration Trigger Threshold Count*, *Acceleration Trigger Threshold Period*, *Acceleration Trigger*

Threshold, and *Acceleration Event Grace Period* registers. These are registers 0x 42, 0x 43, 0x 44, and 0x 45, respectively.

7.4.2.2 Example DL Payloads

- Change threshold value to 800 m*g*:
    - DL payload: 0x **C4 03 20**
        - Register 0x 44 with bit 7 set to 1 = 0x C4
        - 800 m*g* = 0x 03 20
- Read *Acceleration Event Value to Tx*:
    - DL payload: **0x 46**
        - Register 0x 46 with bit 7 set to 0 = 0x 46

8 MCU Temperature Sensing

CHICKADEE can send data for MCU temperature [°C], read from the MCU, in a LoRaWAN UL.

Threshold ranges can also be set such that moving in or out of range causes additional MCU temperature data reports.

In the following subsections, periodic and threshold-based reporting are described.

8.1 Temperature Reporting

8.1.1 Operational Description

CHICKADEE samples temperature readings from the MCU during the background of normal operation. It can be configured to periodically report the temperature in [°C] in a LoRaWAN UL. Sampling cannot be disabled, but reporting can be disabled.

By default, temperature is reported once every hour.

NOTE: During MCU temperature changes, it may take some time for the sensor to report the new MCU temperature values because the air takes some time to flow through the enclosure vents. Results may vary depending on the mounting orientation with respect to air flow direction.

8.1.2 UL Report Frame Formats

MCU temperature data reports are sent on ***LoRaWAN port 10*** and have the frame format as shown in Figure 3-2. The specific details for the frame formats are listed in Table 8-1. For the general description of sensor data report formats and behaviour, see §3.2.1.

Table 8-1: MCU Temperature Data Report UL Frame Formats

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
MCU Temperature	0x 03	0x 67	2 B	Temperature	• [0.1°C/LSb] (signed)	*temperature: <value> (signed/°C)*

8.1.2.1 Example UL Payloads

- **0x 03 67 00 96**
  - Channel ID = 0x 03, Type ID = 0x 67 → MCU temperature data report
  - 0x 00 96 = 150 × 0.1°C = 15°C

8.1.3 Configuration Settings

Table 8-2 shows the list of configuration registers which control periodic MCU temperature data reporting behaviour. In this table, the bit indexing scheme is as shown in Figure 3-1. To access these registers, a command must be formatted and sent according to the details described in §3.3.2.

Table 8-2: MCU Temperature Report Configuration Registers

Address	Name	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 20	Seconds per Core Tick	4 B	Access R/W • Tick value for periodic events • Acceptable values: 15, 16, 17, …, 86400 • Other values: Invalid and ignored	60 s = 1 min **0x 00 00 00 3C**	*seconds_per_core_tick: <value>* *(unsigned/s)*
0x 26	Ticks per MCU Temperature	2 B	Access R/W • Ticks between MCU temperature reports • Acceptable values: 0, 1, 2, …, 65535 • 0 disables periodic temperature reports	60 ticks = 1 hr period **0x 00 3C**	*ticks_per_MCU_temp: <value>* *(unsigned/no unit)*

8.1.3.1 Periodic Reporting Configuration

The MCU temperature reporting periods can be configured using registers 0x 20, and 0x 26, according to the equation described in §4.2.2. That is:

$$\textit{Temperature Reporting Period} = \textit{Seconds per Core Tick} \times \textit{Ticks per Temperature}$$

Setting the reporting period to 0 disables periodic reporting of that data type.

8.1.3.2 Example DL Payloads

- Schedule a temperature report every 48 hours:
  - DL payload: **0x A0 00 00 0E 10 A5 00 30**
    - Register 0x 20 with bit 7 set to 1 = 0x A0
    - 3600 s/core tick = 0x 00 00 0E 10
    - Register 0x 26 with bit 7 set to 1 = 0x A6
    - Report every 48 ticks = 0x 00 30
- Disable temperature reporting:
  - DL payload: **0x A8 00 00**
    - Register 0x 26 with bit 7 set to 1 = 0x A6
    - Disable periodic reporting = 0x 00 00

8.2 Threshold-Based Reporting

8.2.1 Operational Description

In addition to periodic MCU temperature data reporting, CHICKADEE supports sending additional data reports based on crossing configurable thresholds. Temperature thresholds can be set.

When a temperature threshold is enabled, the sensor reports the temperature data when it leaves the configured *threshold window*, and once again when it re-enters the threshold window. The threshold window is an open interval, meaning that even if the temperature data is equal to the *low threshold* or *high threshold*, the sensor is considered to have left the threshold window.

When the temperature data is inside the threshold window, CHICKADEE is in the *idle* sampling state. When outside, CHICKADEE is in the *active* sampling state. This is illustrated using the default configurations in Figure 8-1.

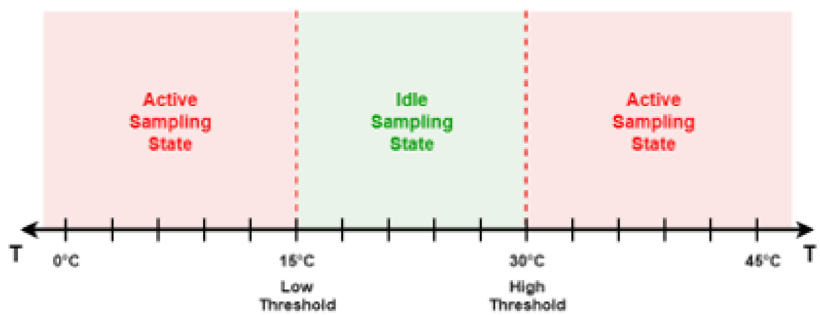


Figure 8-1: Default MCU Temperature Windows

The sampling periods are configurable and determine how often the temperature is checked when the reported value is inside/outside the threshold window. When first enabled, the temperature starts in the idle sampling state.

By default, threshold-based reporting is disabled.

Threshold-based reporting is compatible with periodic reporting of the MCU temperature data; both can be disabled and enabled independently[28].

8.2.2 UL Report Frame Formats

The UL report frame formats for threshold-based reports are identical to those for periodic reports, see §8.1.2.

[28] See §8.1 for details about periodic MCU temperature data reporting configuration.

8.2.3 Configuration Settings

Table 8-3 shows the list of configuration registers which affect temperature vector reporting behaviour. In addition to these registers, the configuration parameters listed in Table 7-1 also affect general accelerometer behaviour. In this table, the bit indexing scheme is as shown in Figure 3-1. To access these registers, a command must be formatted and sent according to the details described in §3.3.2.

Table 8-3: MCU Temperature Data Threshold Configuration Registers

Address	Name	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 60	Temperature Sample Period: Idle	4 B	Access: R/W • Sample period of MCU temperature data when in idle state [1 s/LSB] • Acceptable values: 10, 11, …, 86400 • Other values: Invalid and ignored	60 s **0x 00 00 00 3C**	*temp_sample_period_idle: <value>* *(unsigned/sec)*
0x 61	Temperature Sample Period: Active	4 B	Access: R/W • Sample period of MCU temperature data when in active state [1 s/LSB] • Acceptable values: 10, 11, …, 86400 • Other values: Invalid and ignored	30 s **0x 00 00 00 1E**	*temp_sample_period_active: <value>* *(unsigned/sec)*
0x 62	Low/High Temperature Thresholds	2 B	Access: R/W • Bits 8-15: High MCU temperature threshold (signed) [1°C/LSb] • Bits 0-7: Low MCU temperature threshold (signed) [1°C/LSb] • High threshold ≤ Low threshold: Invalid and ignored	• High threshold = 30°C • Low threshold = 15°C **0x 1E 0F**	*temp_threshold_high: <value>* *(signed/°C)* *temp_threshold_low: <value>* *(signed/°C)*
0x 63	Temperature Thresholds Enabled	1 B	Access: R/W • Bit 0: 0/1: MCU temperature thresholds disabled/enabled • Bits 1-7: RFU	Disabled **0x 00**	*temp_thresholds_enabled: <value>* *(string/no unit)*

8.2.3.1 Operational Configuration

The thresholds enabled registers 0x 62 and 0x 63 enable and disable the MCU temperature threshold-based reporting, respectively. When disabled, the threshold bounds, and sample periods can still be configured.

The threshold bounds are stored in 2-byte registers, with the first byte storing the high threshold and the last byte storing the low threshold. The MCU temperature thresholds are defined by register 0x 62 with a 1°C precision. The high threshold must be greater than the low threshold in both cases.

8.2.3.2 Example DL Payloads

- Enable temperature threshold-based reporting with a window between -10°C and 35°C:
    - DL payload: **0x E2 23 F6 E3 01**
        - Register 0x 62 with bit 7 set to 1 = 0x E2
        - High MCU temperature threshold = 35°C = 0x 23
        - Low MCU temperature threshold = -10°C = 0x F6
        - Register 0x 63 with bit 7 set to 1 = 0x BC
        - Thresholds enabled = 0x 01
- Read current sample periods:
    - DL payload: **0x 60 61**
        - Registers 0x 60 and 0x 61 with bits 7 set to 0 = 0x 60 61

9 System Diagnostics

CHICKADEE has a system diagnostics mechanism for managing and recording resets, transducer failures, and other unexpected operational issues that may arise during sensor usage.

9.1 Sensor Reset Diagnostics

The Sensor tracks and reports the reason for its most recent reset and the number of times it has been reset by each of the three reset types:

- **DL Command or Function Button Reset**: occurs when the sensor receives a downlink (sent on LoRaWAN port 100) containing the sensor reset command or the reset pattern is performed on the function button.
- **Independent Watchdog Reset**: occurs when the system gets locked up due to an unforeseen circumstance.
- **Power Loss Reset**: occurs when the Sensor's battery is removed or experiences a brown-out.

The Sensor increments the corresponding reset counter(s) just before initiating its connection attempt to a LoRaWAN network. Consequently, resets that transpire between the Sensor's initial boot-up and its first join request may not be accounted for. To preserve this information across "soft" resets (such as push-button resets, DL command resets, or independent watchdog resets), the Sensor stores the reset counter values in reset-safe RAM.

It is important to note that in the event of a power loss reset, all four reset counters will be reset to zero, while the power loss reset counter will be set to 1.

9.2 Sensor Error Diagnostics

The sensor counts abnormal failures that occur during operation. Usually, it will also attempt to internally surgically resolve such issues without disrupting the overall system operation.

I2C Bus failure: An internal communication bus error has occurred which may result in lost or bad data from the sensor

LPGNSS clock sync failure: The LPGNSS has not received clock sync from the LoRaCloud server and cannot get fixes.

9.3 UL Frame Report Format

Upon a successful JOIN event, CHICKADEE sends the diagnostics reports as part of the first set of uplinks. System diagnostics reports are sent on ***LoRaWAN port 5*** and have the frame format as shown in section 3.2.1. The specific details for the uplink frame formats are listed in Table 9-1.

Table 9-1: Ambient Environment Data Report UL Frame Formats

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Sensor Reset Diagnostics	0x40	0x06	5 B	Reset History	• Bits 0-7: MCU push-button reset counter • Bits 8-15: SW reset counter • Bits 16-23: Independent watchdog reset counter • Bits 24-31: Power loss reset counter • Bits 32-39: Latest reset reason code 0x01 = Push-button reset 0x02 = SW reset (incl. DL request) 0x04 = Independent watchdog reset 0x10 = Power loss reset 0x80 = Other resets	*reset_diagnostics {* *reset_reason: <value>, (string/no unit)* *power_loss_reset_count: <value>, (unsigned/no unit)* *watchdog_reset_count: <value>, (unsigned/no unit)* *sw_reset_count: <value>, (unsigned/no unit)* *button_reset_count: <value> (unsigned/no unit)* *}*
Sensor Error Diagnostics	0x40	0x07	3 B	Error History	• Bits 0-7: I2C Bus Failure • Bits 8-15: Barometer Failure • Bits 16-23: RFU	*error_diagnostics {* *barometer_failure: <value>, (string/no unit)* *i2c_failure: <value>, (string/no unit)* *}*
Sensor Assertion Diagnostics	0x40	0x08	8 B	Assertion info	• Bits 32-63: LR • Bits 0-31: PC	
Sensor Battery Life Diagnostics	0x40	0x09	4 B	Coulomb info	• Bits 0-31: Total coulomb count in mC	
		0x0a	8 B	Current info	• Bits 32-63: Period system current in uA • Bits 0-31: Average system current in uA	

9.3.1 Example UL Payloads

- **0x 40 06 02 01 00 03 04**
    - Channel ID = 0x 40, Type ID = 0x 06 → sensor reset diagnostics
    - 0x 02 = latest reset reason code: SW reset,
    - 0x 01 = power loss reset count: 1,
    - 0x 00 = watchdog reset count: 0,
    - 0x 03 = SW reset count: 3,
    - 0x 04 = push button reset count: 4

- **0x 40 07 00 03 01**
    - Channel ID = 0x 40, Type ID = 0x 07 → sensor error diagnostics
    - 0x 00 = RFU,
    - 0x 03 = barometer failure: 3,
    - 0x 01 = i2c bus failure: 1

9.4 Configuration Settings

The read-only register for querying the system diagnostics report is tabulated in Table 9-2. This query code must be sent on *port 5* to request for the latest systems diagnostics report.

Table 9-2: Systems Diagnostics Configuration Registers

Address	Name	Access	Description
0x40	Systems Diagnostics Query	R only	Query systems diagnostics information from sensor

9.4.1 Example DL Payloads

- Read latest systems diagnostics report
    - DL payload: **0x 40**

Appendix 1 – List of UL Frame Formats

A1-1: LoRaWAN **Port 10** UL Frame Formats

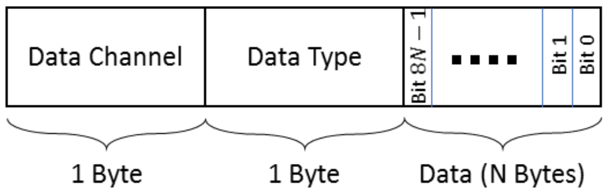


Figure A1-1: UL Frame Format for Sensor Data or GNSS Report

Table A1-1: Complete List of LoRaWAN Port 10 Sensor Data Frame Formats

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
GNSS-Position Coordinates	0x00	0x88	8 B	Coordinates	• Bits 40-63: Latitude (signed, $\frac{90^{\circ}}{2^{23}}$/LSB) • Bits 16-39: Longitude (signed, $\frac{180^{\circ}}{2^{23}}$/LSB) • Bits 0-15: [Altitude] + 500m (unsigned, $\frac{9500}{2^{16}}$ m/LSB)	*coordinates {* *latitude: <value> (number/°)* *longitude: <value> (number/°)* *altitude: <value> (number/m)* *}*

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
GNSS - UTC Timestamp	0x00	0x85	4 B	Timestamp	• Bits 0-5: Second [0-60][29] • Bits 6-11: Minute [0-59] • Bits 12-16: Hour [0-23] • Bits 17-21: Day [1-31] • Bits 22-25: Month [1-12] • Bits 26-31: [Year]—2020	*utc_timestamp {* *year: <value> (number/2020(<value>))* *month: <value> (number/year)* *day: <value> (number/day)* *hour: <value> (number/hour)* *minute: <value> (number/min)* *second: <value> (number/s)* *}*
GNSS-Ground Speed	0x00	0x92	1 B	Speed	0.27778 m/s/LSB	*ground_speed: <value> (number/m/s)*
Remaining Battery Capacity	0x 00	0x D3	1 B	Percentage	• 1% / LSb (unsigned)	*rem_batt_capacity: <value> (unsigned/%)*
Remaining Battery Lifetime	0x 00	0x BD	2 B	Days	• 1 day / LSb (unsigned)	*rem_batt_days: <value> (unsigned/days)*

[29] The maximum possible value for "second" is 60 to allow for leap seconds.

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Geolocation Cycle Failed	0x 00	0x 95	1 B	Bitmap Input	• Bits 0-1: LPGNSS Scan ○ 00: Scan failed ○ 11: Scan successful or scan not done • Bit 2: Wi-Fi scan ○ 0: Scan failed ○ 1: Scan successful or scan not done • Bit 3: BLE scan ○ 0: Scan failed ○ 1: Scan successful or scan not done • Bit 4: LoRaWAN duty cycle ○ 0: LPGNSS and/or Wi-Fi scan results dropped due to duty cycle restrictions ○ 1: No duty cycle restriction impacts • Bits 5-6: GNSS Scan ○ 00: Scan failed ○ 11: Scan successful or scan not done Bit 7: 0 (RFU)	*geolocation_cycle_failed: {* *gnss: <value>, (unsigned/no unit)* *wi_fi: <value>, (unsigned/no unit)* *ble: <value>, (unsigned/no unit)* *duty_cycle: <value>, (unsigned/no unit)* *}*
Acceleration Alarm Status	0x 00	0x 00	1 B	Digital Input	• 0x 00 = Alarm inactive (motion no longer detected) • 0x FF = Alarm active (motion detected)	*acceleration_alarm (unsigned/no unit)*
Acceleration Vector	0x 00	0x 71	6 B	Acceleration	• [1 m*g*/LSb] (signed) • Bits 32-47: X-axis acceleration • Bits 16-31: Y-axis acceleration • Bits 0-15: • Z-axis acceleration	*acceleration_vector {* *xaxis: <value>, (signed/g)* *yaxis: <value>, (signed/g)* *zaxis: <value> (signed/g)* *}*
MCU Temperature	0x 03	0x 67	2 B	Temperature	• [0.1°C/LSb] (signed)	*temperature: <value> (signed/°C)*

A1-2: LoRaWAN **Port 25** UL Frame Formats

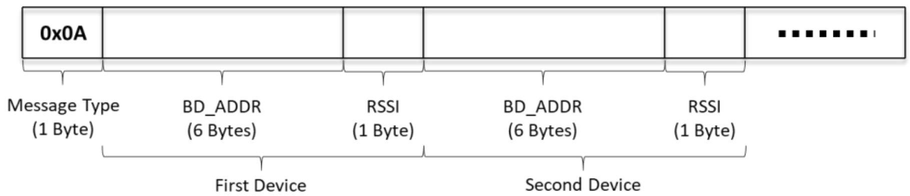


Figure A1-2: The BLE Report UL Payload Format for Basic Reporting

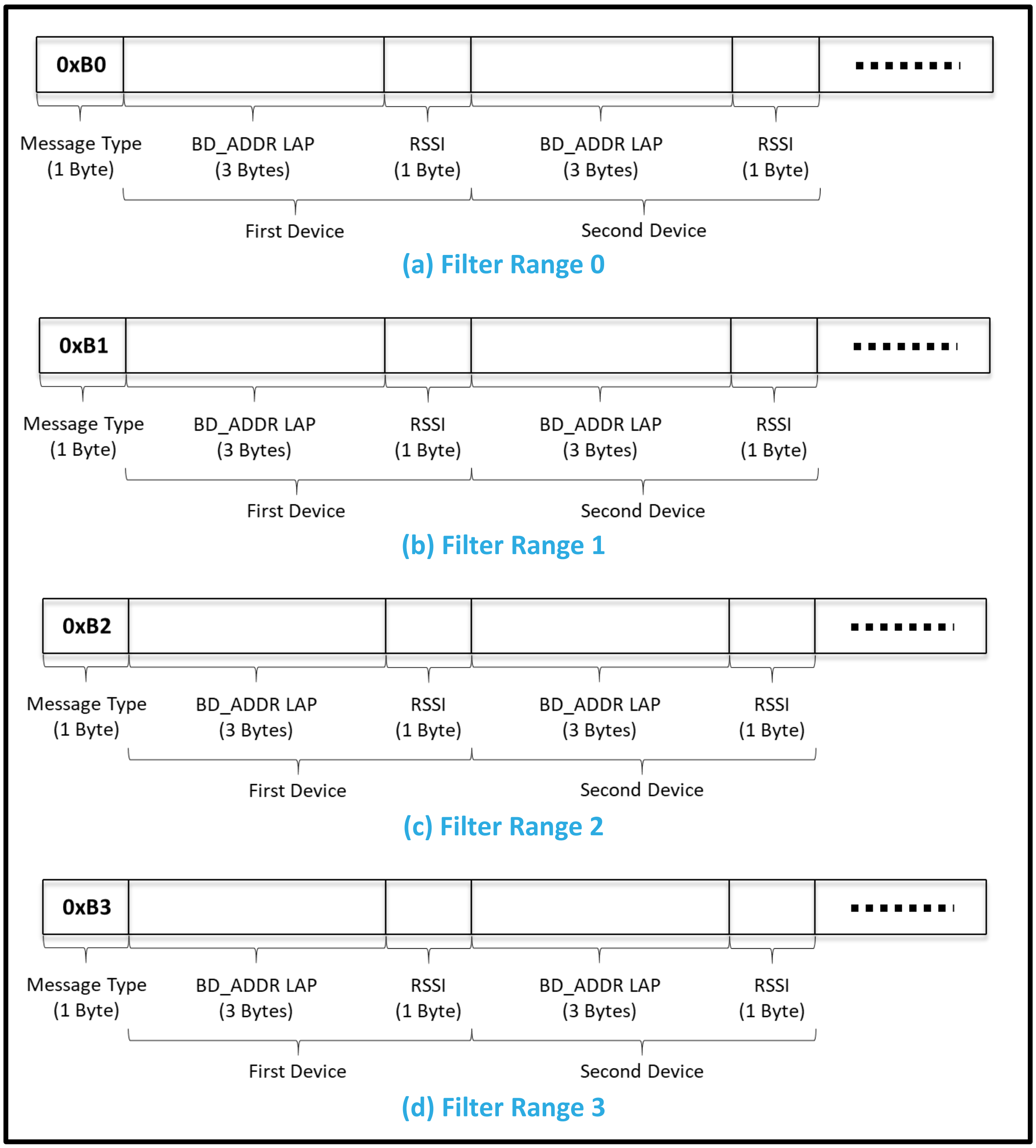


Figure A1-3: BLE Report UL Payload Formats for Filtered Reporting

A1-3: LoRaWAN Port 100 and 101 UL Frame Formats

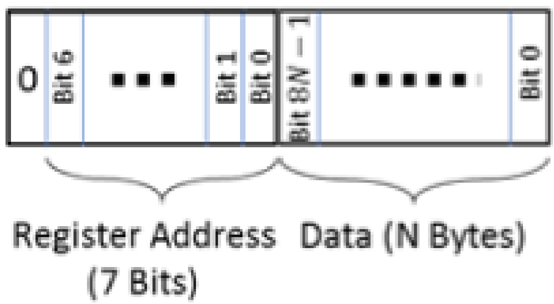


Figure A1-4: LoRaWAN Port 100 Read Response Format

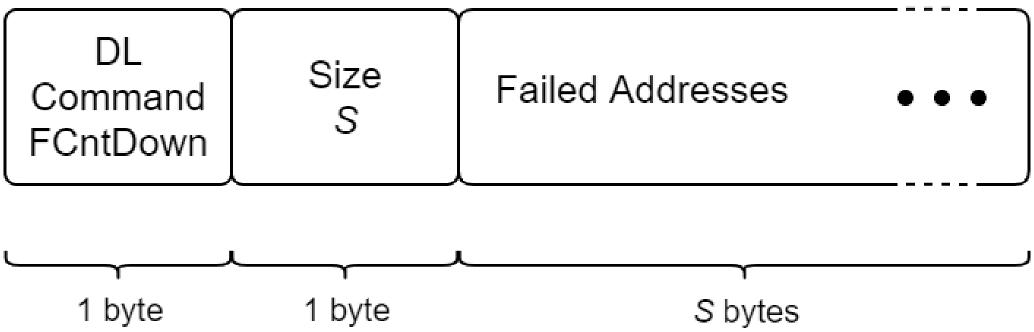


Figure A1-5: LoRaWAN Port 101 Write/Error Response Format

A1-4: LoRaWAN Port 192 and 197 UL Frame Formats

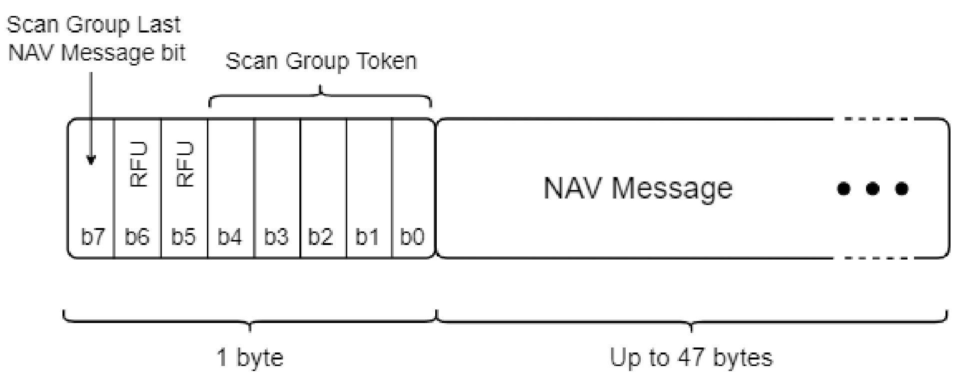


Figure A1-6: LoRaWAN Port 192 LPGNSS Scan Results UL Frame Format

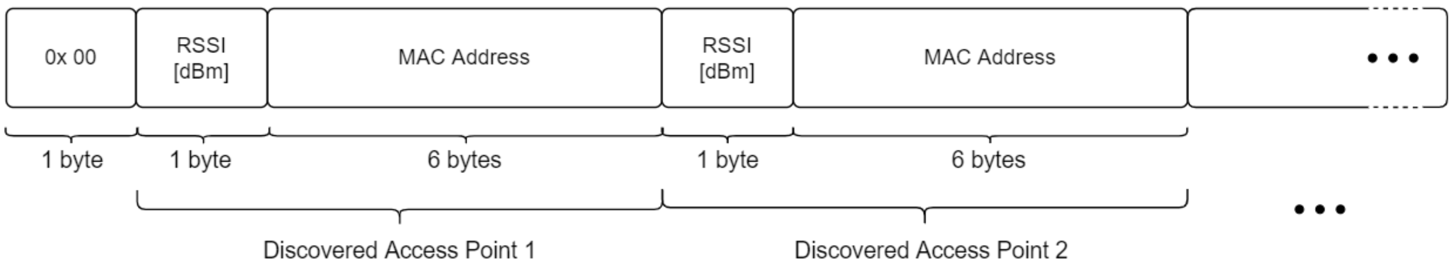
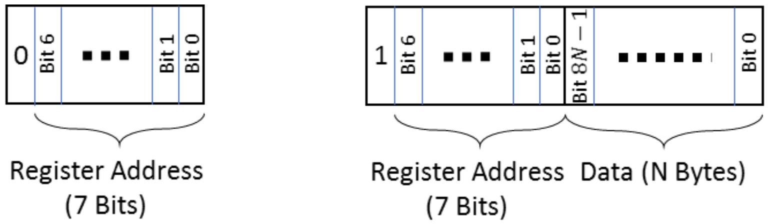


Figure A1-7: LoRaWAN Port 197 Wi-Fi Scan Results UL Frame Format

Appendix 2 – Lists of Configuration Registers and DL Payload Formats (Port 100)



a) Read Command Block (b) Write or Executable Command Block

Figure A2-1: LoRaWAN Port 100 DL Formats for Configuration and Control Message Blocks

Table A2-1: Complete List of Configuration Registers (Port 100)

Address	Name	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 0A	Tracker / Beacon Mode	1 B	Access: R/W • 0x 00 = Tracker Mode • 0x 01 = Beacon Mode	Tracker Mode **0x 00**	*tracker_beacon_mode: <value> (unsigned/no unit)*
0x 11	LoRaMAC Options	2 B	Access: R/W (bits 1 and 2 are RO) • Bit 0: 0/1 = Unconfirmed/Confirmed UL • Bit 1 = 1 (RO): 0/1 = Private/Public Sync Word • Bit 2 = 1 (RO): 0/1 = Duty Cycle disabled/enabled • Bit 3: 0/1 = Disable/Enable ADR • Bits 4-15: RFU	• Unconfirmed UL • Public Sync Word • Duty cycle enabled • ADR disabled **0x 00 06**	*loramac_opts: { confirm_mode: <value>, (unsigned/no unit) sync_word: <value>, (unsigned/no unit) duty_cycle: <value>, (unsigned/no unit) adr: <value> (unsigned/no unit) }*
0x 12	LoRaMAC DR and Tx Power[30]	2 B	Access: R/W • Bits 8-11: Default DR number • Bits 0-3: Default Tx power number • Bits 4-7, 12-15: Ignored	• DR3 • Tx Power 0 (max power; see Table 4-2) **0x 03 00**	*loramac_dr_tx: { dr_number: <value>, (unsigned/no unit) tx_power_number: <value> (unsigned/no unit) }*
0x 20	Seconds per Core Tick	4 B	Access R/W • Tick value for periodic events • Acceptable values: 15, 16, 17, …, 86400 • Other values: Invalid and ignored	60 s = 1 min **0x 00 00 00 3C**	*seconds_per_core_tick: <value> (unsigned/s)*

[30] Tx power number *m* translates to the maximum Tx power, which is a function of the LoRaWAN RF region, minus $2 \times m$ dB [1]

Address	Name	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 21	Ticks per Battery	2 B	Access R/W • Ticks between battery reports • Acceptable values: 1, 2, 3, …, 65535 0: Invalid and ignored	1440 ticks = 1 day period **0x 05 A0**	*ticks_per_battery: <value>* *(unsigned/no unit)*
0x 22	Ticks per Geolocation Update in STILL State	2 B	Access R/W • Ticks between geolocation scan cycles when the sensor is not in motion • Acceptable values: 0, 1, 2, …, 65535 0 disables periodic geolocation updates when not in motion	60 ticks = 1 hr period **0x 00 3C**	*ticks_per_geolocation_update_stillness: <value>* *(unsigned/no unit)*
0x 23	Ticks per Geolocation Update in MOBILE State	2 B	Access R/W • Ticks between geolocation scan cycles when the sensor is in motion • Acceptable values: 0, 1, 2, …, 65535 0 disables periodic geolocation updates when in motion	10 ticks = 10 min period **0x 00 0A**	*ticks_per_geolocation_update_mobility: <value>* *(unsigned/no unit)*
0x 24	Ticks per Geolocation Update in EMERGENCY State	2 B	Access R/W • Ticks between geolocation scan cycles when the sensor is in EMERGENCY state • Acceptable values: 0, 1, 2, …, 65535 0 disables periodic geolocation updates when in EMERGENCY state	4 ticks = 4 min period **0x 00 04**	*ticks_per_geolocation_update_emergency: <value>* *(unsigned/no unit)*
0x 25	Ticks per Accelerometer	2 B	Access R/W • Ticks between accelerometer vector reports • Acceptable values: 0, 1, 2, …, 65535 0 disables periodic accelerometer vector reports	Periodic reporting disabled **0x 00 00**	*ticks_per_accelerometer: <value>* *(unsigned/no unit)*
0x 26	Ticks per Temperature	2 B	Access R/W • Ticks between MCU temperature reports • Acceptable values: 0, 1, 2, …, 65535 0 disables periodic temperature reports	60 ticks = 1 hr period **0x 00 3C**	*ticks_per_MCU_temp: <value>* *(unsigned/no unit)*

Address	Name	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 30	Geolocation Strategy	1 B	Access: R/W • Bits 0-1: 1st priority scan ○ 01: BLE ○ 10: WIFI ○ 11: LPGNSS ○ 00: Invalid and ignored • Bits 2-3: 2nd priority scan ○ 00: Not defined ○ 01: BLE ○ 10: WIFI ○ 11: LPGNSS • Bits 4-5: 3rd priority scan ○ 00: Not defined ○ 01: BLE ○ 10: WIFI ○ 11: LPGNSS • Bits 6-7: Scan order logic option (see Table 5-2) ○ 00: A ○ 01: B ○ 10: C ○ 11: D • Restrictions: ○ 2nd scan must be defined to set 3rd scan ○ Scan types can only be defined once	• 1st priority scan: LPGNSS or GNSS • 2nd priority scan: Wi-Fi • 3rd priority scan: BLE • Scan order logic option A **0b 00 00 01 10 11** or **0x 1B**	*geolocation_strategy: {* *scan_1: <value>, (unsigned/no unit)* *scan_2: <value>, (unsigned/no unit)* *scan_3: <value>, (unsigned/no unit)* *scan_order_logic: <value>, (unsigned/no unit)* *}*
0x 36	LPGNSS Assist Coordinates	8 B	Access: R/W • Bit 0: ○ 0/1: disable/enable assist coordinates • Bits 1-15: RFU • Bits 16-39: Longitude *y* [(180°/2^{23})/LSb ≈ 0.00002°/LSb] **Acceptable values: -180 ≤ *y* ≤ 180** • Bits 40-63: Latitude *x* [(90°/2^{23})/LSb ≈ 0.00001°/LSb] **Acceptable values: -90 ≤ *x* ≤ 90**	• Assist coordinates disabled • x = 0° • y = 0° **0x 00 00 00 00 00 00 00 00 00**	*assist_coordinates: {* *latitude: <value>, (signed/°)* *longitude: <value>, (signed/°)* *enabled: <value>, (unsigned/no unit)* *}*
0x 3F	GNSS Receiver	1 B	Access: R/W • 0x 00 = LPGNSS • 0x 01 = GNSS	LPGNSS **0x 00**	*gnss_receiver: <value> (unsigned/no unit)*
0x 40	Accelerometer Mode	1 B	Access: R/W • Bit 0: 0/1 = X-axis disabled/enabled • Bit 1: 0/1 = Y-axis disabled/enabled • Bit 2: 0/1 = Z-axis disabled/enabled • Bits 3-6: Ignored • Bit 7: 0/1 = Accelerometer off/on	• X-axis enabled • Y-axis enabled • Z-axis enabled • Accelerometer on • **0x 87**	*accl_mode: {* *xaxis_enabled: <value>, (unsigned/no unit)* *yaxis_enabled: <value>, (unsigned/no unit)* *zaxis_enabled: <value>, (unsigned/no unit)* *power_on: <value> (unsigned/no unit)* *}*

Address	Name	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 41	Accelerometer Sensitivity	1 B	Access: R/W • Bits 0-2: Sample Rate: 1/2/3/4/5/6/7 = 1/10/25/50/100/200/400 Hz 0: Invalid and ignored • Bits 4-5: Measurement Range: 0/1/2/3 = ±2/±4/±8/±16 *g* • Bits 3, 6, 7: Ignored	• Sample Rate = 10 Hz • Measurement Range = ±8 *g* **0x 22**	*accl_sensitivity: {* *sample_rate: <value>, (unsigned/Hz)* *measurement_range: <value> (unsigned/g)* *}*
0x 42	Acceleration Trigger Threshold Count	2 B	Access: R/W • Number of above-threshold acceleration samples before an acceleration trigger is registered • Acceptable values: ≥ 1 • 0: Invalid and ignored	1 trigger **0x 00 01**	*accl_trigger_threshold_count: <value>* *(unsigned/no unit)*
0x 43	Acceleration Trigger Threshold Period	2 B	Access: R/W • Period over which acceleration samples are counted for trigger detection [1s/LSb] • Acceptable values: ≥ 5 • 0-4: Invalid and ignored	10 seconds **0x 00 0A**	*accl_trigger_threshold_period: <value>* *(unsigned/s)*
0x 44	Acceleration Trigger Threshold	2 B	Access: R/W • Acceleration magnitude threshold for acceleration trigger [1 m*g*/LSb]	250 *mg* **0x 00 FA**	*accl_trigger_threshold: <value>* *(unsigned/mg)*
0x 45	Acceleration Event Grace Period	2 B	Access: R/W • Time to pass after the last accelerometer trigger before the event is cleared [1s/LSb] • Acceptable values: ≥ 15 • 0-14: Invalid and ignored	5 min **0x 01 2C**	*accl_event_grace_period: <value>* *(unsigned/s)*
0x 46	Acceleration Event Value to Tx	1 B	Access: R/W • Bit 0: 0/1 = Acceleration alarm UL report disabled/enabled • Bit 1: 0/1 = Accelerometer Assist for geolocation disabled/enabled • Bits 2-7: RFU	• Acceleration alarm report UL enabled • Accelerometer Assist enabled **0x 03**	*accl_tx: {* *accl_alarms: <value>, (unsigned/no unit)* *accl_assist: <value>, (unsigned/no unit)* *}*

Address	Name	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 4A	Battery Report Options	1 B	Access: R/W • Bit 1: 0/1 = Remaining battery capacity [%] not reported/reported • Bit 2: Remaining battery lifetime [days] not reported/reported • Bits 1-2 all set to 0: Invalid and ignored • Bits 0, 3-7: RFU	Remaining battery capacity [%] and remaining battery lifetime [days] reported **0x 06**	*battery_tx: {* *report_capacity_enabled: <value>,* *(unsigned/no unit)* *report_lifetime_enabled: <value>* *(unsigned/no unit)* *}*
0x 50	BLE Rx Mode	1 B	Access: R/W • Bits 0-6: ***N*** Number of reported devices (1–127) 0: Disables BLE Rx mode • Bit 7: 0/1 = Averaging mode off/on	• Up to 8 reported devices • Averaging mode on **0x 88**	*ble_mode: {* *num_reported_devices: <value>,* *(unsigned/no unit)* *averaging_mode: <value>* *(unsigned/no unit)* *}*
0x 51	BLE Scan Duration	2 B	Access: R/W • Bits 0-7: Scan duration [1 s/LSb] Acceptable values: 1, 2, …, 10 0: Invalid and ignored • Bits 8-15: RFU	3 s **0x 00 03**	*ble_scan_duration: {* *periodic: <value>,* *(unsigned/no unit)* *}*
0x 52	BLE Scan Interval	2 B	Access: R/W • Scan interval [1 ms/LSb] • Acceptable values: "Scan Window", …, 10 000 • Other values: Invalid and ignored	30 ms **0x 00 1E**	*ble_scan_interval: <value>* *(unsigned/sec)*
0x 53	BLE Scan Window	2 B	Access: R/W • Scan window [1 ms/LSb] • Acceptable values: 3, …, "Scan Interval" • Other values: Invalid and ignored	30 ms **0x 00 1E**	*ble_scan_window: <value>* *(unsigned/sec)*
0x 54	Filter Range 0	9 B	Access: R/W • Range 0 for filtered BD_{ADDR}s • $B_0:B_1:B_2:B_3:B_4:B_5$ to $B_0:B_1:B_2:B_6:B_7:B_8$ ▪ OUI = $B_0:B_1:B_2$ ▪ $LAP_{start} = B_3:B_4:B_5$ ▪ $LAP_{end} = B_6:B_7:B_8$	Range inactive **0x 00 00 00 00 00 00 00 00 00**	*filter_range_0: {* *oui: <value>,* *(unsigned/no unit)* *lap_start: <value>,* *(unsigned/no unit)* *lap_end: <value>* *(unsigned/no unit)* *}*

Address	Name	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 55	Filter Range 1	9 B	Access: R/W • Range 1 for filtered BD_{ADDR}s • $B_0:B_1:B_2:B_3:B_4:B_5$ to $B_0:B_1:B_2:B_6:B_7:B_8$ ▪ OUI = $B_0:B_1:B_2$ ▪ LAP_{start} = $B_3:B_4:B_5$ ▪ LAP_{end} = $B_6:B_7:B_8$	Range inactive **0x 00 00 00 00 00 00 00 00 00**	*filter_range_1: {* *oui: <value>, (unsigned/no unit)* *lap_start: <value>, (unsigned/no unit)* *lap_end: <value> (unsigned/no unit)* *}*
0x 56	Filter Range 2	9 B	Access: R/W • Range 2 for filtered BD_{ADDR}s • $B_0:B_1:B_2:B_3:B_4:B_5$ to $B_0:B_1:B_2:B_6:B_7:B_8$ ▪ OUI = $B_0:B_1:B_2$ ▪ LAP_{start} = $B_3:B_4:B_5$ ▪ LAP_{end} = $B_6:B_7:B_8$	Range inactive **0x 00 00 00 00 00 00 00 00 00**	*filter_range_2: {* *oui: <value>, (unsigned/no unit)* *lap_start: <value>, (unsigned/no unit)* *lap_end: <value> (unsigned/no unit)* *}*
0x 57	Filter Range 3	9 B	Access: R/W • Range 3 for filtered BD_{ADDR}s • $B_0:B_1:B_2:B_3:B_4:B_5$ to $B_0:B_1:B_2:B_6:B_7:B_8$ ▪ OUI = $B_0:B_1:B_2$ ▪ LAP_{start} = $B_3:B_4:B_5$ ▪ LAP_{end} = $B_6:B_7:B_8$	Range inactive **0x 00 00 00 00 00 00 00 00 00**	*filter_range_3: {* *oui: <value>, (unsigned/no unit)* *lap_start: <value>, (unsigned/no unit)* *lap_end: <value> (unsigned/no unit)* *}*
0x 58	BLE Advertising Enable / Disable	1 B	Access: R/W • Bits 7-1: Ignored • Bit 0: 0/1 = Advertising disabled/enabled	Advertising disabled **0x 00**	*advertising_enabled: <value> (unsigned/no unit)*
0x 59	BLE Advertising Interval	2 B	Access: R/W • Advertising interval [1 ms/LSb] • Acceptable values: 100 ms – 10240 ms • Other values: Invalid and ignored	100 ms **0x 00 64**	*min_advertising_interval: <value> (unsigned/ms)*

Address	Name	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 5B	BLE Tx Advertising Power	1 B	Access: R/W • BLE Tx Power [dBm] ▪ 0x 00 = 0 dBm ▪ 0x 01 = -0.85 dBm ▪ 0x 02 = -1.8 dBm ▪ 0x 03 = -3.15 dBm ▪ 0x 04 = -4 dBm ▪ 0x 05 = -4.95 dBm ▪ 0x 06 = -5.9 dBm ▪ 0x 07 = -6.9 dBm ▪ 0x 08 = -7.8 dBm ▪ 0x 09 = -8.85 dBm ▪ 0x 0A = -9.9 dBm ▪ 0x 0B = -12.05 dBm ▪ 0x 0C = -14.1 dBm ▪ 0x 0D = -16.5 dBm ▪ 0x 0E = -20.85 dBm ▪ 0x 0F = -40 dBm • Other values: Invalid and ignored	0 dBm **0x 00**	*tx_advertising_power: <value>* *(unsigned/no unit)*
0x 5C	BLE Advertisement Packet Format	1 B	Access: R/W • Bit 0: 0/1 = iBeacon advertising disabled/enabled • Bit 1: 0/1 = Eddystone UID advertising disabled/enabled • Bit 2: 0/1 = Eddystone TLM advertising disabled/enabled • Bits 3-7: RFU • All set to 0: Invalid and ignored	• iBeacon enabled • Eddystone UID disabled • Eddystone TLM disabled **0x 01**	*advertising_packet_format: {* *ibeacon: <value>, (unsigned/no unit)* *eddystone_uid: <value>, (unsigned/no unit)* *eddystone_tlm: <value> (unsigned/no unit)* *}*
0x 5F	BLE MAC Address	6 B	Access: RO The 6-Byte BLE Device MAC address, BD_{ADDR}, of the sensor.	Unique for every sensor	*mac_address: <value>* *(unsigned/no unit)*
0x 60	Temperature Period: Idle	4 B	Access: R/W • Sample period of MCU temperature data when in idle state [1 s/LSB] • Acceptable values: 10, 11, …, 86400 Other values: Invalid and ignored	60 s **0x 00 00 00 3C**	*temp_sample_period_idle: <value>* *(unsigned/sec)*
0x 61	Temperature Period: Active	4 B	Access: R/W • Sample period of MCU temperature data when in active state [1 s/LSB] • Acceptable values: 10, 11, …, 86400 Other values: Invalid and ignored	30 s **0x 00 00 00 1E**	*temp_sample_period_active: <value>* *(unsigned/sec)*

Address	Name	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 62	Low/High Temperature Thresholds	2 B	Access: R/W • Bits 8-15: High MCU temperature threshold (signed) [1°C/LSb] • Bits 0-7: Low MCU temperature threshold (signed) [1°C/LSb] High threshold ≤ Low threshold: Invalid and ignored	• High threshold = 30°C • Low threshold = 15°C **0x 1E 0F**	*temp_threshold_high: <value> (signed/°C)* *temp_threshold_low: <value>* *(signed/°C)*
0x 63	Temperature Thresholds Enabled	1 B	Access: R/W • Bit 0: 0/1: MCU temperature thresholds disabled/enabled • Bits 1-7: RFU	Disabled **0x 00**	*temp_thresholds_enabled: <value>* *(string/no unit)*
0x 70	Flash Write Command	2 B	Access: W • Bit 14: 0/1 = Do not write/Write LoRaMAC Configuration • Bit 13: 0/1 = Do not write/Write App Configuration • Bit 0: 0/1 = Do not restart/Restart Sensor • Bits 1-12, 15: RFU (0, otherwise invalid)	N/A	*write_to_flash {* *app_config: <value>, (unsigned/no unit)* *lora_config: <value>, (unsigned/no unit)* *restart_sensor: <value> (unsigned/no unit)* *}*
0x 71	FW Metadata	7 B	Access: R • Bits 48-55: App version major • Bits 40-47: App version minor • Bits 32-39: App version revision • Bits 24-31: LoRa Basics modem version major • Bits 16-23: LoRa Basics modem version minor • Bits 8-15: LoRa Basics modem version revision • Bits 0-7: LoRaMAC region number[31]	N/A	*metadata {* *app_ver_major: <value>, (unsigned/no unit)* *app_ver_minor: <value>, (unsigned/no unit)* *app_ver_revision: <value>, (unsigned/no unit)* *modem_ver_major: <value>, (unsigned/no unit)* *modem_ver_minor: <value>, (unsigned/no unit)* *modem_ver_revision: <value>, (unsigned/no unit)* *loramac_region: <value> (unsigned/no unit)* *}*

[31] Defined by Table 4-7.

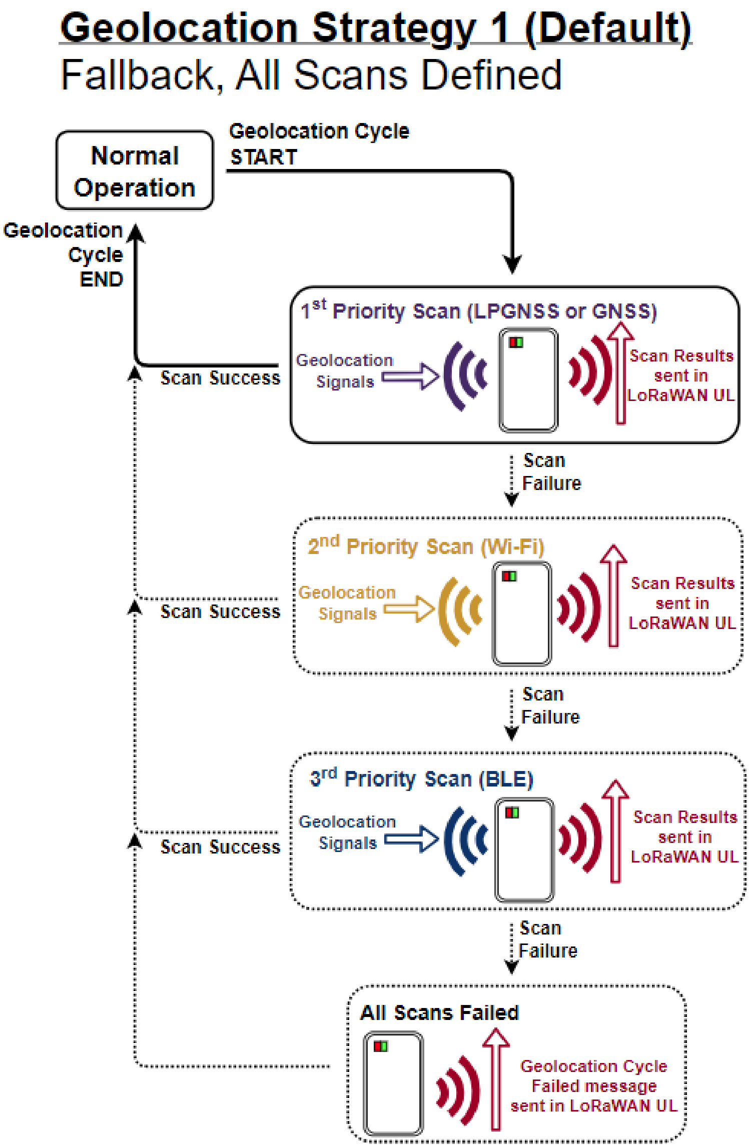
Address	Name	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 72	Reset Configuration to Factory Defaults	1 B	Access: W • 0x 0A: Reset app configuration • 0x B0: Reset LoRaMAC configuration • 0x BA: Reset both App and LoRaMAC configurations • Any other value: Invalid and ignored	N/A	*config_factory_reset {* *app_config: <value>, (unsigned/no unit)* *loramac_config: <value> (unsigned/no unit)* *}*
0x 73	BLE Metadata	6 B	Access: RO • Bits 16-23: BLE stack version major • Bits 8-15: BLE stack version minor • Bits 0-7: BLE stack version revision • Bits 24-47: RFU	N/A	*ble_metadata {* *stack_ver_major: <value>, (unsigned/no unit)* *stack_ver_minor: <value>, (unsigned/no unit)* *stack_ver_revision: <value>, (unsigned/no unit)* *}*

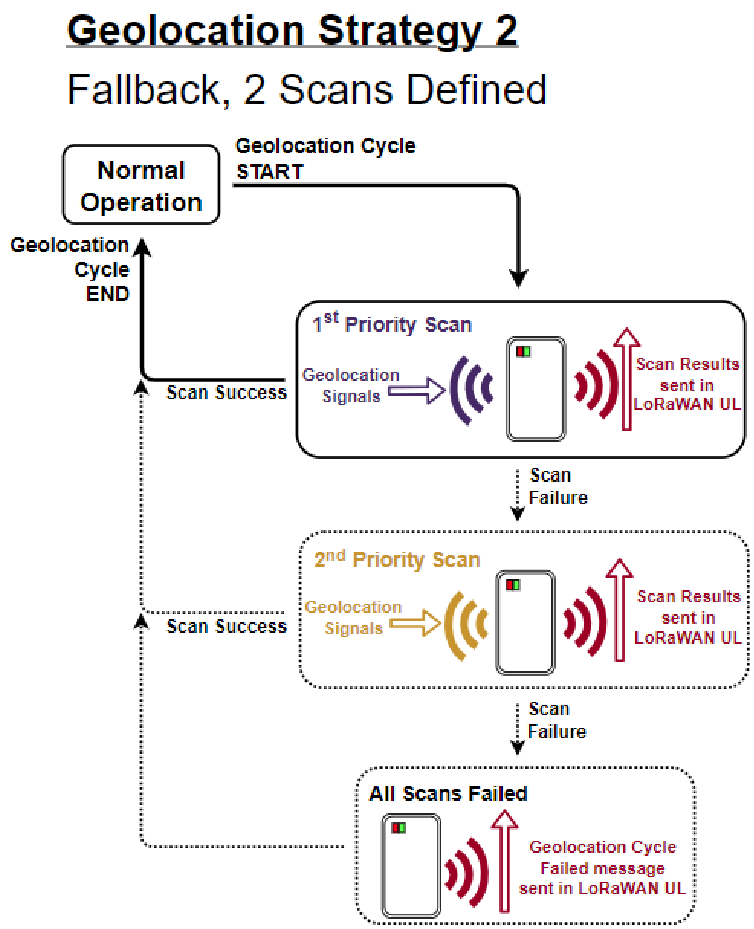
Table A2-2: Comparison of Default Configuration Values for Tracker and Beacon Mode

Name	Register Address [Hex]	Default Value, Tracker Mode [Hex]	Default Value, Beacon Mode [Hex]	Category
Tracker/Beacon Mode	0A	00: Tracker Mode is default		BLE
LoRaMAC Options	11	00 06	00 06	LoRaMAC Options
LoRaMAC DR and Tx Power	12	03 00	**00 00**	
Seconds per Core Tick	20	00 00 00 3C	00 00 00 3C	Periodic Reporting
Ticks per Battery	21	05 A0	05 A0	
Ticks per Geolocation Update in STILL State	22	00 3C	**00 00**	
Ticks per Geolocation Update in MOBILE State	23	00 0A	**00 00**	
Ticks per Geolocation Update in EMERGENCY Stage	24	00 04	**00 00**	
Ticks per Accelerometer	25	00 00	00 00	
Ticks per Temperature	26	00 3C	00 3C	
Geolocation Strategy	30	1B	1B	Geolocation
GNSS Receiver	3F	00	00	
Accelerometer Mode	40	87	**07**	Accelerometer
Accelerometer Sensitivity	41	22	22	
Acceleration Trigger Threshold Count	42	00 01	00 01	
Acceleration Trigger Threshold Period	43	00 0A	00 0A	
Acceleration Trigger Threshold	44	07 D0	07 D0	
Acceleration Event Grace Period	45	01 2C	01 2C	
Acceleration Event Value to Tx	46	03	**01**	
Battery Report Options	4A	06	06	Battery Management
Mode	50	88	88	BLE Scanning (Tracker Mode)
Scan Duration	51	00 03	00 03	
Scan Interval	52	00 1E	00 1E	
Scan Window	53	00 1E	00 1E	
Filter Range 0	54	00 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00 00	
Filter Range 1	55	00 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00 00	
Filter Range 2	56	00 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00 00	
Filter Range 3	57	00 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00 00	
Advertising Enable / Disable	58	00	**01**	BLE Advertising (Beacon Mode)
Advertising Interval	59	00 64	00 64	
Tx Advertising Power	5B	00	00	
Advertisement Packet Format	5C	01	01	
BLE MAC Address	5F	Unique for every device		
Temperature Sample Period: Idle	60	00 00 00 3C	00 00 00 3C	MCU Temperature Sensing
Temperature Sample Period: Active	61	00 00 00 1E	00 00 00 1E	
Low/High Temperature Thresholds	62	1E 0F	1E 0F	
Temperature Thresholds Enabled	63	00	00	

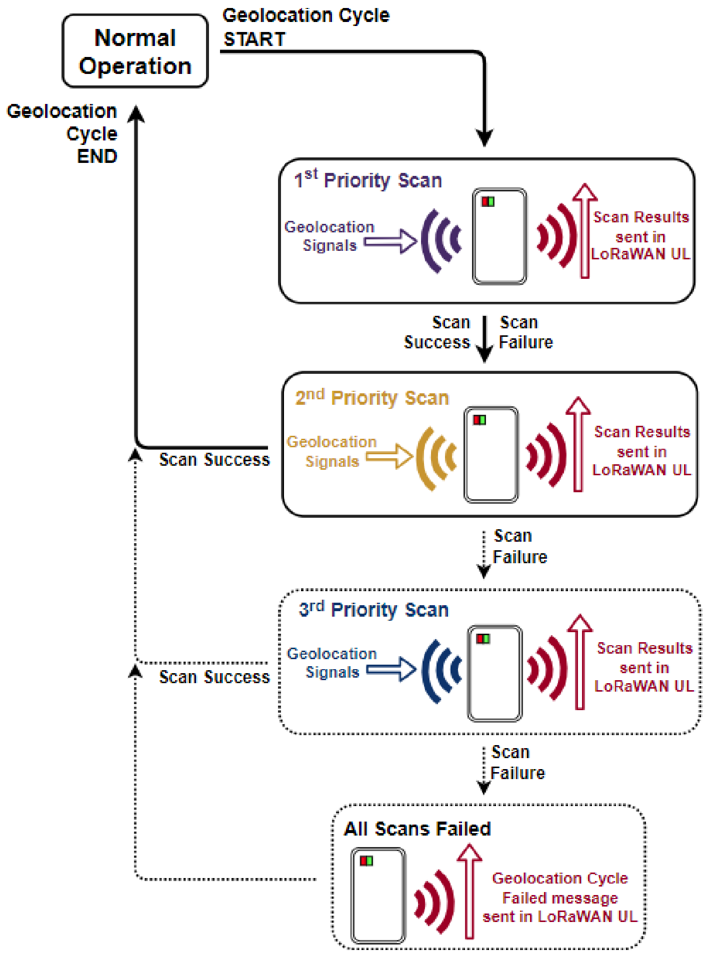
Appendix 3 – List of Geolocation Strategies

Solid lines: process always done. Dotted lines: process done under certain conditions.

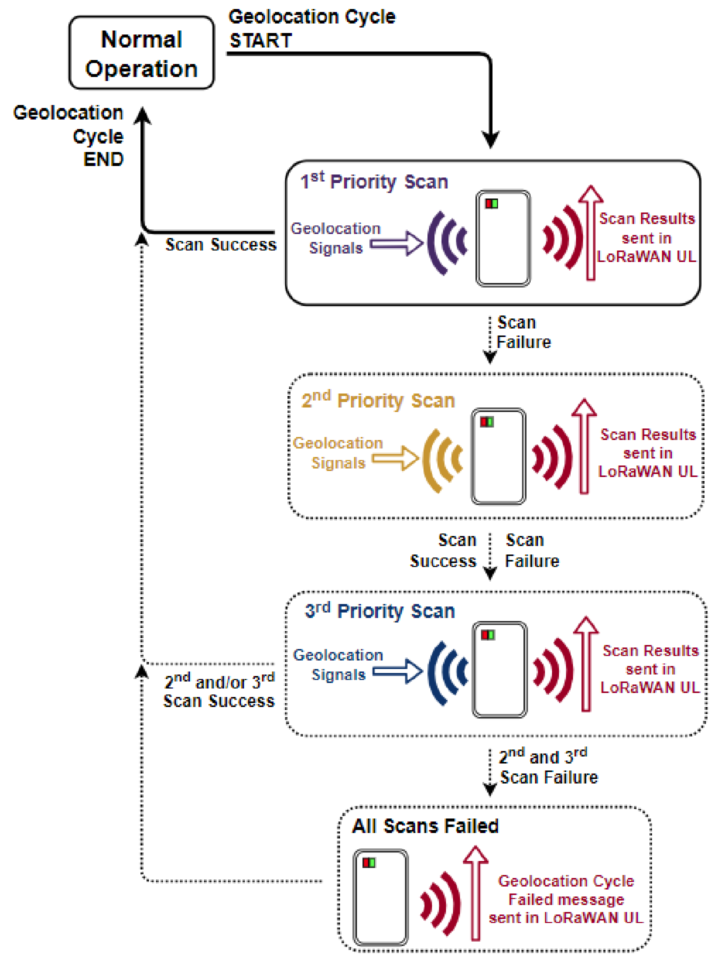




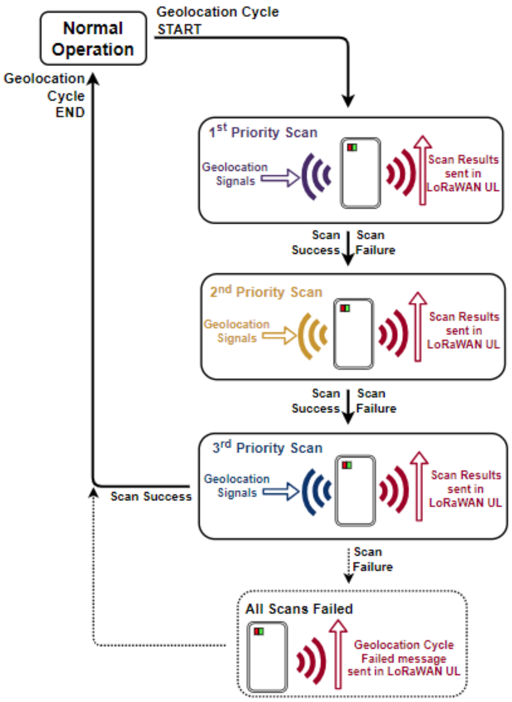
Geolocation Strategy 3
1 Backup, All Scans Defined



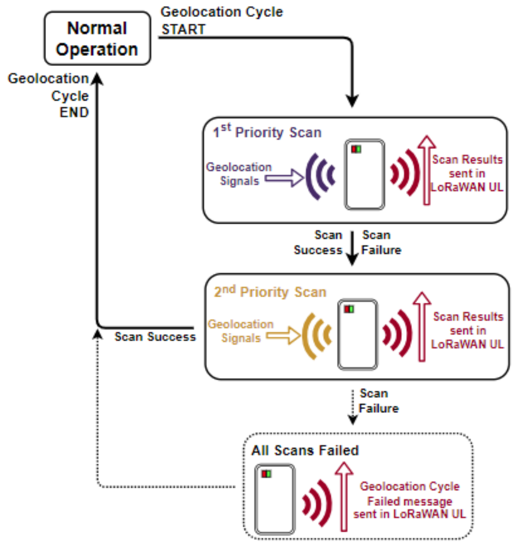
Geolocation Strategy 4
2 Backups, All Scans Defined



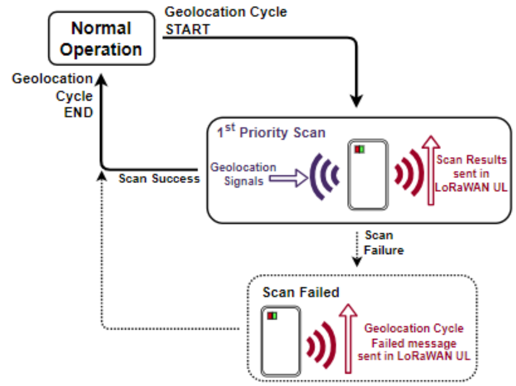
Geolocation Strategy 5
All Scans, All Scans Defined



Geolocation Strategy 6
All Scans, 2 Scans Defined



Geolocation Strategy 7
All Scans, 1 Scan Defined



Appendix 4 – Troubleshooting Guide

A4-1: Clock Sync

On occasion, clock sync requests that occur shortly after a CHICKADEE device has joined the NS will not get answered back with a downlink from LoRa Cloud. A user can recognize this when repeated uplinks beginning with 0x **17 01** on port **199** (in excess of two upon joining the NS) are being sent from the CHICKADEE device to LoRa Cloud, and no LPGNSS scan results are forwarded to LoRa Cloud on port 192. If this occurs, ensure the token entered in LeapX is correct. The token is a long character string and is case sensitive.

A4-2: Almanac

On occasion, almanac requests could become "stuck", meaning that they are repeatedly sent to LoRa Cloud and not answered back with downlinks. A user can recognize this when there are multiple uplinks containing 0x **18 02** and no downlinks containing 0x **01 00 0A** in return. If this occurs, send a downlink of 0x **00 00 0A 6F BF 00 00 04** to port **199**. This downlink will "reset" the almanac handshaking between the device and LoRa Cloud. One additional step that must be taken is to reset the device. If it is desired to save configuration of both application and LoRa settings, the downlink is 0x **F0 60 01** to port **100**[32]. If the device is not reset, LPGNSS scans will no longer work, and the next defined scan type will take place[33]. The reset DL must be sent as **unconfirmed**.

[32] For more information on saving configuration and device reset, see §4.4.2 and §4.4.3.

[33] For more information on scan cycle operation, see §5.1.

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[4] LoRa Alliance, "LoRaWAN Regional Parameters," September 2022. [Online]. Available: https://resources.lora-alliance.org/home/rp002-1-0-4-regional-parameters.

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