

STORK

Asset Tracker

Technical Reference Manual

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Revision History

| TRM Version | Date | Editor | FW Version | Comments |
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| 0.1 | September 06, 2023 | Ade Adegboye | 0.0.1 | <ul style="list-style-type: none"> • First draft (based on T0008710_TRM_v0.1_Draft and T0006940_UG_ver1.1) |
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| 2.0 | November 21, 2023 | Carter Mudryk | 1.0.0 | <ul style="list-style-type: none"> • Updated TRM to new function-based structure. • Updated anti-bricking strategy to reflect global sensor specifications. • Changed geolocation scan cycle period definitions to tick registers 0x 22 and 0x 23. • Changed register addresses for ticks per temperature and RH to 0x 25 and 0x 26, respectively. • Changed default values of periodic report periods. • Removed legacy command response option support. • Changed default geolocation strategy scan priorities. • Changed the bit indexing scheme of register 0x 36. • Added GNSS diagnostics reporting description. • Restricted maximum BLE scan duration to 10 s. • Restricted minimum BLE advertising interval to 100 ms. • Updated operational descriptions in more detail. • Updated list of acronyms. • Changed default value of register 0x 11. • Changed definition of LoRaMAC version number to LoRa Basics Modem version number in register 0x 71. |

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List of Acronyms

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

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 §5.4.4.

This document contains the technical information about the supported functionality of the TEKTELIC *STORK Asset Tracker*, referred to as the *STORK* 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

The STORK is a low-power LoRaWAN IoT sensor run on a single C-cell LTC battery and packed into a compact IP67 polycarbonate casing. Its primary purpose is to track assets indoors and outdoors using a combination of location-tracking technologies:

- **Low-Power GNSS:** Outdoor tracking using satellite geolocation.
- **Wi-Fi Sniffing:** Outdoor and/or indoor tracking using Wi-Fi access point geolocation.
- **BLE Tracking:** Indoor tracking using BLE beacon network localization.

The STORK is meant to be a component in an end-to-end asset tracking solution as shown in Figure 1-1.

NOTE: Only raw scan data is present in the LoRaWAN payloads, not sensor location information. In order to track and visualize a STORK'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 STORK 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* [1].

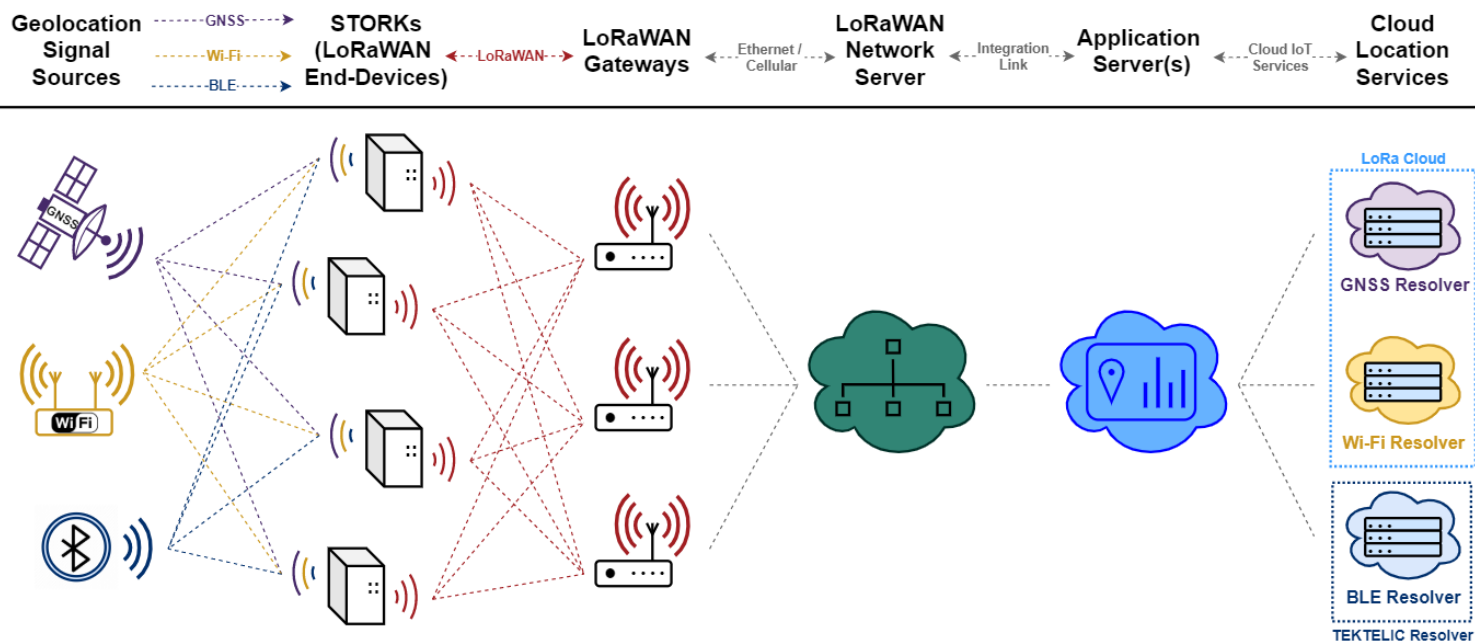


Figure 1-1: STORK Asset Tracking End-to-End Architecture

The asset location information flows in this order:

1. The STORK conducts 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 (GWs)*.
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. TEKTELIC's *LOCUS* application is designed to work natively with STORK, but any compatible 3rd-party application can be used.
6. The respective location resolver service processes the raw scan data to calculate a position fix.
 - a. GNSS and Wi-Fi scan data messages are designed to be processed by Semtech's *LoRa Cloud* service, but any compatible cloud service can be used.
 - b. BLE scan data messages are designed to be processed by TEKTELIC's *Geolocation Resolver Backend (GRB)*, but any compatible cloud service can be used.

7. The resolved fixes are returned to the application where they can then be visualized on a virtual dashboard.

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

- **LoRaWAN:** The LoRa wireless communications standard protocol. This technology provides a low-bandwidth, low-power, and long-range¹ 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. The STORK supports LoRa and (G)FSK modulations according to the LoRaWAN L2 1.0.4 Specification [2]. The 150 MHz-960 MHz ISM bands are utilized to meet different application requirements from the standards and proprietary protocols of the given region.
- **Core design:** Based on the low-power, IoT-targeted STM32WB55CWU6 MCU, which runs the system SW and has a built-in BLE module. The LR1110 transceiver from Semtech handles the LoRa, GNSS, and Wi-Fi 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 of interest.
- **BLE beacon mode:** In this mode, the sensor broadcasts BLE advertisements which make it discoverable by other nearby trackers or BLE-capable devices.
- **Ambient environment sensing:** The temperature and relative humidity of the surrounding environment 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 up to 4.3 years with default settings², or 16 months with default Beacon mode settings³.
- **Magnetic detection:** A magnet can be used to wake from the DEEP SLEEP state (used for shipping) and to force ULs during normal operation.

¹ Up to 2 km NLoS and more than 22 km LoS.

² Default settings with 8 hours of movement and 16 hours of stillness, operating at DR3 in the US region.

³ Default settings with no event-based reports, operating at DR3 in the US 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: STORK HW Models

| Product Code, Module-Level T-Code | Product Code, PCBA-Level T-Code | Model Name | Description | LoRaWAN Regions Supported ⁴ |
|-----------------------------------|---------------------------------|------------|--------------------------------------|--|
| T0008375 | T0008357 | STORK | GNSS-Wi-Fi-BLE Asset Tracking Sensor | EU868 |
| | | | | US915 |

Table 1-2: List of STORK Information Streams

| Stream Direction | Data Type | Sent on LoRaWAN Port [decimal] |
|-------------------|--|--------------------------------|
| UL (Sensor to NS) | Reports containing sensor data: <ul style="list-style-type: none"> • Battery life data • Accelerometer vectors and alarms • Ambient temperature • Ambient RH • Geolocation cycle failed message | 10 |
| | Reports containing GNSS diagnostic information | 16 |
| | Reports containing discovered BLE device data | 25 |
| | Responses to read/write configuration and control commands | 100/101 |
| | GNSS scan results to be forwarded to LoRa Cloud | 192 |
| | 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 |

⁴ Other regional variants available upon request.

Table 1-3: STORK Default Reporting Behavior

| Report | Report Type | Default Periodicity |
|----------------------------|-----------------|--|
| Battery data | Periodic | 24 hours |
| | Event-based | When magnetic sensor is triggered |
| Geolocation Update | Periodic | 10 min when in motion 1 hour when still |
| Acceleration vector | Periodic | Disabled |
| Accelerometer motion alarm | Event-based | When motion is detected When sensor becomes still |
| Ambient temperature | Periodic | 1 hour |
| | Threshold-based | Disabled |
| Ambient RH | Periodic | 1 hour |
| | Event-based | Disabled |

1.3 Scope

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

- Magnetic Function
- External User Interfacing
- General Configuration Settings and LoRaWAN Payload Formats
- Basic Operation
 - LoRaMAC Options
 - Periodic Report Scheduling
 - Battery Management
 - General Command and Control Operations
- Geolocation
 - Scan Cycle and Resolving GNSS, Wi-Fi, and BLE Locations
 - GNSS Diagnostic Information
- BLE Operation
 - Tracker Mode
 - Beacon Mode
- Accelerometer Operation
 - General Sampling Behaviour
 - Orientation Detection
 - Motion Detection Alarms
 - Accelerometer Assist for Geolocation
- Ambient Environment Sensing
 - Temperature and RH Reporting
 - Threshold-Based Reporting

2 Magnetic Function

The STORK is equipped with an internal hall-effect sensor, which detects the presence and absence of a magnet. A magnet will be detected if it is sufficiently strong and brought into contact with the enclosure at the *magnetic activation site*, which is located on the enclosure body at the magnet symbol on the front, as shown in Figure 2-1.

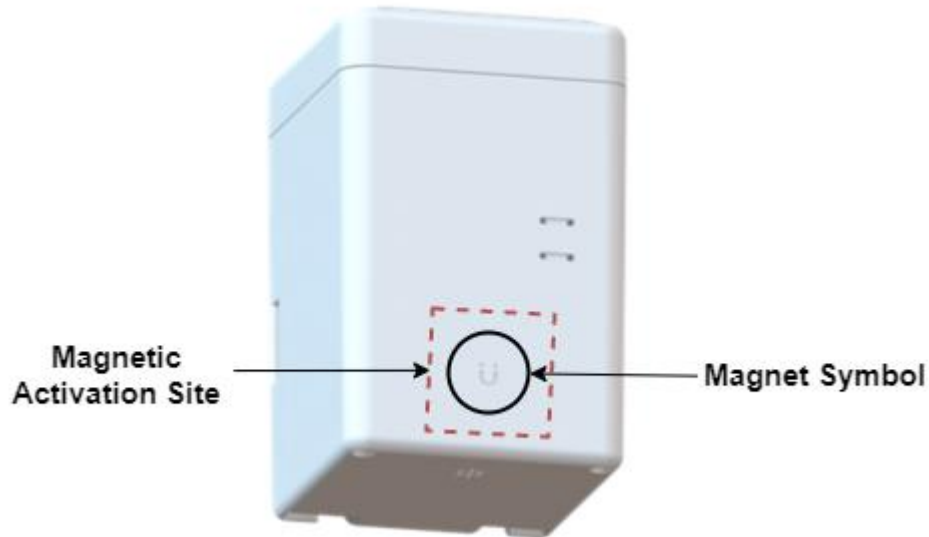


Figure 2-1: Enclosure View Showing Magnetic Activation Site and Symbol

There are 3 main magnetic functions of the STORK:

1. Waking from DEEP SLEEP or entering DEEP SLEEP.
2. Sensor reset.
3. Forced ULs.

2.1 DEEP SLEEP

2.1.1 Sensor Activation

When a STORK exits the factory, it is put into low-power DEEP SLEEP mode to conserve battery life during shipping and storage. To activate the sensor and wake it from DEEP SLEEP, the user must apply a *magnetic activation/reset pattern*.

The magnetic activation/reset pattern is illustrated in Figure 2-2. A “magnet presence” is achieved by placing a magnet against the enclosure at the magnetic activation site as shown in Figure 2-1. A “magnet absence” is achieved by taking the magnet away from the enclosure. Figure

2-2 shows that the pattern involves sustaining a “magnet presence” continuously for at least 3 sec but less than 10 sec.

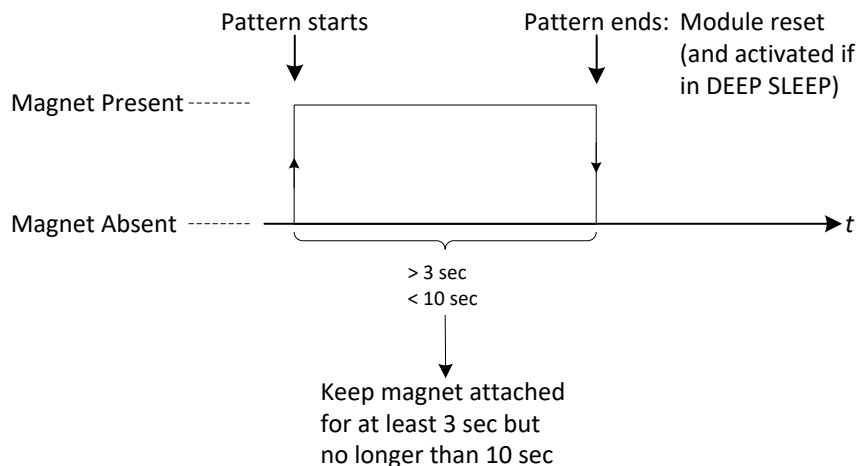


Figure 2-2: The Magnetic Activation/Reset Pattern.

When the magnetic activation/reset pattern is applied to the sensor it displays an LED indication (described in §3.1.3) to show that it has accepted the pattern. In all cases, this pattern causes the sensor to reset. If the sensor was in DEEP SLEEP when the pattern was applied, after resetting it will wake up and begin trying to join the network⁵.

2.1.2 Re-entering DEEP SLEEP

There are 2 methods for putting the sensor into DEEP SLEEP mode:

1. **Magnetic Activation/Reset Pattern:** The same pattern to wake the sensor from DEEP SLEEP (Figure 2-2) can be used to put the sensor back into DEEP SLEEP, if applied while the sensor is in JOIN mode. I.e.: If the sensor detects the magnetic pattern before it has received the JOIN ACCEPT DL, then it will re-enter DEEP SLEEP mode.
2. **OTA DL Command:** If the sensor has already joined the network and is in normal operation mode, a DL can be sent to remotely put it into DEEP SLEEP mode. The frame payload must contain the single byte **0x 00** and the DL must be sent on **LoRaWAN port 99** as explained in §4.3.1.

After completing either of these methods, the magnetic activation/reset pattern will then be required to bring this sensor back out of DEEP SLEEP, as usual.

⁵ The very first time a sensor is activated out of the box or after a battery replacement, there might be some ramp-up time required due to battery passivation. See §5.3.1.2 for details.

2.2 Sensor Reset

If the sensor is in normal operation - already joined to the network and not still in JOIN mode - applying the magnetic activation/reset pattern as described in §2.1.1 will cause it to reset. After resetting, the sensor will enter JOIN mode and begin attempting to join the network.

2.3 Forced Uplinks

As a Class-A LoRaWAN end-device, the sensor only opens LoRaWAN receive windows immediately following uplink transmissions [3]. It is therefore useful to be able to force the sensor to UL so that it can receive DL commands from the NS ahead of its next scheduled periodic report.

The magnetic pattern for forced ULs involves briefly tapping the magnet against the magnetic activation site then removing it in less than 2 seconds, as illustrated in Figure 2-3. The magnetic activation site is shown in Figure 2-1.

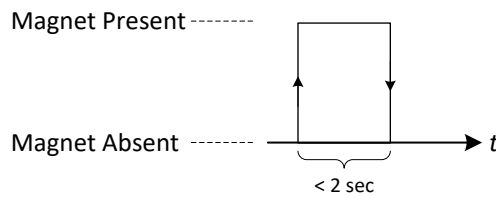


Figure 2-3: The Magnetic Forced UL Pattern

The magnetic forced UL has a payload which contains a regular battery report on **LoRaWAN port 10**, as described in §5.3.2.

NOTE: Mistakenly holding the magnet against the magnetic activation site for more than 3 s may trigger a module reset, as explained in §2.2

3 External User Interfacing

The STORK enclosure is shown in Figure 3-1 and the locations of the external user interfacing are identified. The LED behaviour is described in the following subsection. The humidity vents allow for air circulation for better ambient temperature and RH measurements.

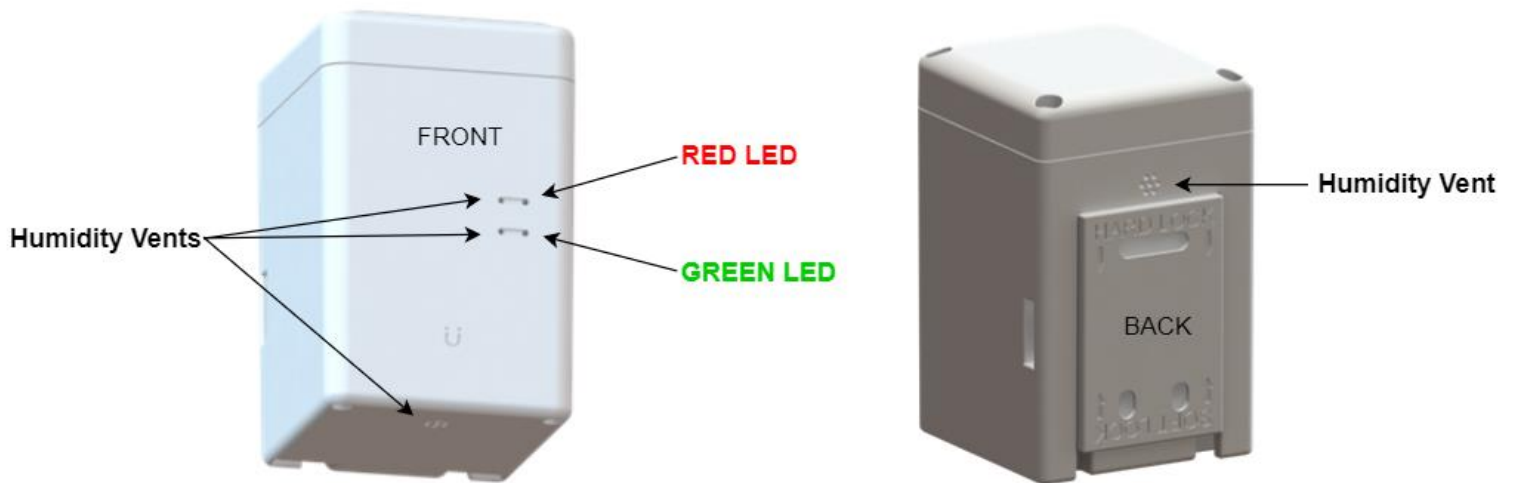


Figure 3-1: External User Interfacing on the STORK Enclosure

3.1 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 3-1. 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 3-1. The detailed sequence and timings for each are described in the following subsections.

Table 3-1: 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 |
| 3 quick RED flashes | Entering DEEP SLEEP |

3.1.1 Power-On and Network Join Patterns

When the sensor is activated or reset:

1. Both **GREEN** and **RED** are OFF for approximately 0.5 s after any reset occurs.
2. Upon startup, the SW conducts its POST. Both **GREEN** and **RED** are turned on when the POST begins.
3. When the POST ends (about 2 s), both **GREEN** and **RED** are turned off. Immediately following, the sensor will do 1 of 2 things, depending on the POST result:
 - a. If the POST passes, **GREEN** is toggled ON and OFF 3 times: every 100 ms for 0.6 s, as shown in Figure 3-2. In this case, the LED pattern proceeds to step 4.
 - b. If the POST fails, **RED** is toggled ON and OFF 3 times: every 100 ms for 0.6 s, as shown in Figure 3-2. In this case, the device restarts and the LED pattern begins again at step 1 after approximately 4 s.

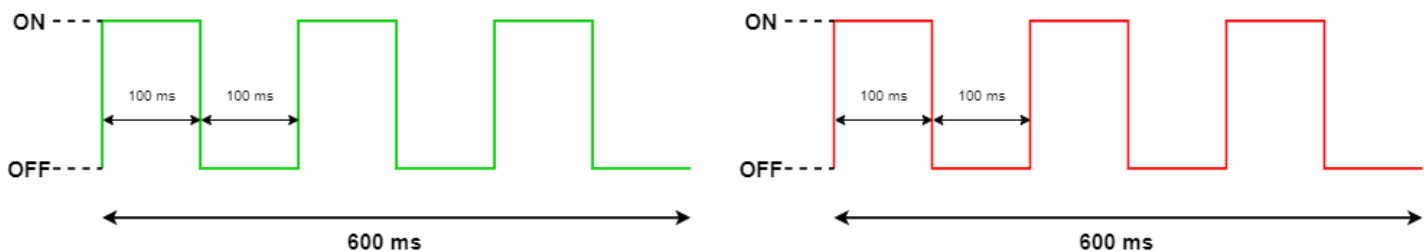


Figure 3-2: The GREEN POST Pass (left) and RED POST Failure (right) LED Patterns

4. After a successful POST, both **GREEN** and **RED** are turned off. Immediately following this, the sensor will enter JOIN mode and begin attempting to join the network. For the first hour⁶:
 - a. **GREEN** is toggled ON and OFF every 50 ms for the first hour.
 - b. **RED** flashes just once:
 - i. with a pulse duration of 25 ms right after transmitting a JOIN REQUEST. This occurs at approximately 40 s intervals at the beginning of the join process, but at decreasing regularity the longer the join process continues due to battery saving measures and possible duty-cycle limitations in certain regions [4].

⁶ The very first time a sensor is activated out of the box or after a battery replacement, there might be some ramp-up time required due to battery passivation. See §5.3.1.2 for details.

- ii. with a pulse duration of 100 ms right after receiving a JOIN ACCEPT. This will occur once, after which, the device will have joined the network and normal operation begins.

If the sensor has been unsuccessfully trying to join for more than an hour, it enters *join back-off* to conserve power. While the sensor still attempts to join, **GREEN** stops flashing and **RED** flashes twice (ON time: 10 ms, OFF time: 10 ms) every 8 s. The JOIN LED pattern is shown in Figure 3-3

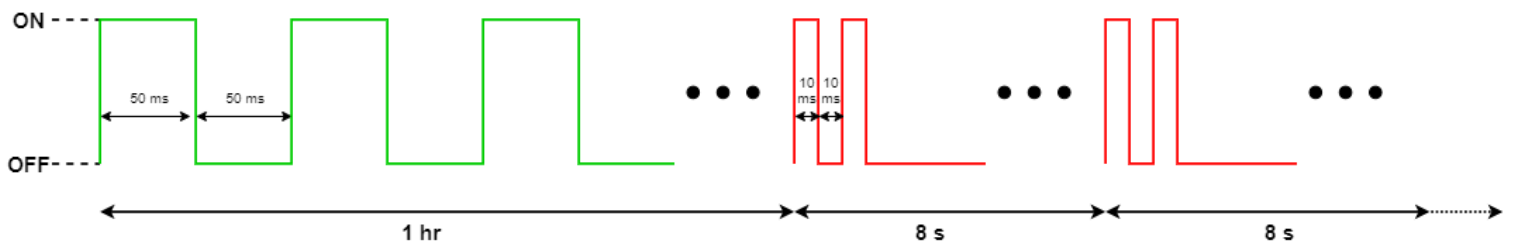


Figure 3-3: The LED Patterns During JOIN Mode

3.1.2 Normal Operation Patterns

After the sensor has joined the network:

- a. **RED** flashes just once with a pulse duration of 25 ms right after transmitting an uplink.
- b. **GREEN** flashes just once with a pulse duration of 100 ms right after receiving a downlink.

3.1.3 DEEP SLEEP and Magnetic Reset Patterns

The sensor displays an LED indication when it is brought out of DEEP SLEEP or reset by applying the magnetic pattern. The following LED pattern is displayed about 3 sec after the pattern is applied:

1. **GREEN** is turned ON for 75 ms, then turned OFF.
2. After a 100-500 ms pause while the device resets, the normal Power-On and Network Join LED patterns described in §3.1.1 occur.

There is another LED pattern for when the device is put back into DEEP SLEEP. The following LED pattern is displayed about 3 s after the pattern is applied:

1. After a 100-500 ms pause while the device resets, the Power-On POST LED patterns described in steps 1-3 in §3.1.1 occur.

2. Immediately, **RED** is toggled ON and OFF 3 times: every 100 ms for 0.6 sec as shown in Figure 3-4.

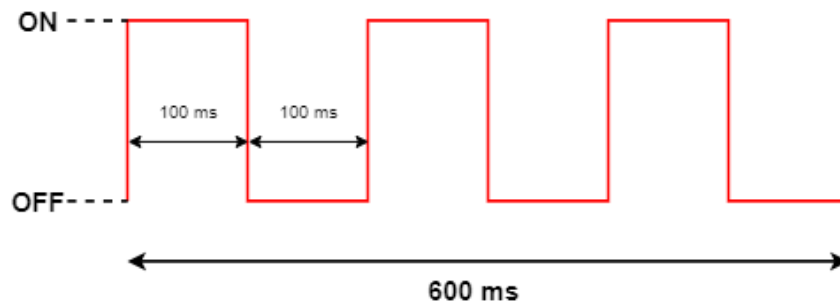


Figure 3-4: The RED LED Pattern Before Entering DEEP SLEEP

4 General Configuration Settings and LoRaWAN Payload Formats

The STORK communicates with the NS using LoRaWAN packets [3]. 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 the STORK.

There is an online application called *KONA ATLAS* available as a comprehensive packet codec tool [5]. It supports encoding DL payloads and decoding UL payloads for STORK.

4.1 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 4-1.



Figure 4-1: 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 §4.3.2.

Not every register is utilized in the current STORK SW; some are RFU. These registers are locked and inaccessible for R/W.

For a complete summary list of the specific definitions, sizes, and default values of all configuration registers, see Table 0-3 in Appendix 2.

4.2 UL Payload Formats

UpLinks (ULs) are LoRaWAN packets sent from the sensor to the NS. They are used for the following purposes in STORK⁷:

1. **Reports** containing real time sensor data.
2. **Responses** to configuration and control commands⁸.
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 4-1.

Table 4-1: UL Information Streams

| Data Type | Sent on LoRaWAN Port [decimal] |
|--|--------------------------------|
| Reports containing sensor data: <ul style="list-style-type: none"> • Battery life data • Accelerometer vectors and alarms • Ambient temperature • Ambient RH • Geolocation cycle failed messages | 10 |
| Reports containing GNSS diagnostic information | 16 |
| Reports containing discovered BLE device data | 25 |
| Responses to read/write configuration and control commands | 100/101 |
| GNSS scan results to be forwarded to LoRa Cloud | 192 |
| Wi-Fi scan results to be forwarded to LoRa Cloud | 197 |
| LoRa Cloud requests | 199 |

4.2.1 Sensor Data Reports (LoRaWAN Port 10 ULs)

This section describes general frame formats. For a complete summary list of specific LoRaWAN port 10 UL frame formats, refer to Table 0-1 in Appendix 1. The specific frame details are also included in the corresponding function-specific sections: §5.3.2 (battery data), §8.2.2 (accelerometer vector), §8.3.2 (accelerometer alarms), §6.1.2 (geolocation data), and §9.1.2 (temperature and RH data).

⁷ 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].

⁸ See §4.3.2 for a description of configuration and control commands.

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 §5.2.
- **Event-Based Reporting:** Various external events can trigger unscheduled sensor data reports on interrupt. These events include motion detection, stillness detection, magnetic presence detection, temperature threshold breaches, and RH threshold breaches. Each event elicits a different type of response from the sensor. Not all event-based reporting is enabled by default.

The following sensor data types are sent in reports on **LoRaWAN port 10**:

- Remaining battery capacity
- Remaining battery lifetime
- Failed geolocation scan message
- Acceleration alarm
- Acceleration vector
- Ambient temperature
- Ambient RH

The **LoRaWAN port 10** UL report payload is encoded in a general frame format shown in Figure 4-2. A big-endian format (MSb/MSB first) is always followed. This format is the same for both periodic and even-based reports.

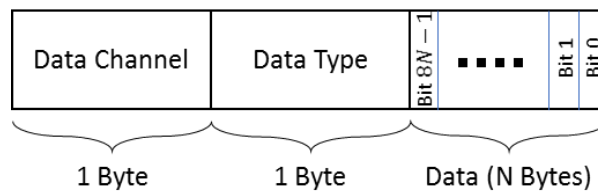


Figure 4-2: The UL Frame Format of a Sensor Data Report

A single sensor data report payload can include multiple data frames from different sensing components and these frames can be arranged in any order.

4.2.2 GNSS Diagnostic Reports (LoRaWAN Port 16 ULs)

GNSS diagnostic information is sent in reports on **LoRaWAN port 16** (when enabled). The general frame format is the same as for other sensor data reports as shown in Figure 4-2. See §6.2.2 for a description of GNSS diagnostic reporting behaviour. See Table 0-2 in Appendix 1 for a summary of the specific frame formats.

4.2.3 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 §7.1.2 for a complete description of BLE reporting behaviour. See Figure 0-2 and Figure 0-3 in Appendix 1 for a summary of the frame formats.

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

The sensor sends ULs in response to any DLs received which contain configuration and control commands⁹. 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.

4.2.4.1 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 [4]). The bit indexing scheme is the same as for configuration registers, which is shown in Figure 4-1.

If the sensor receives a read command trying to access a register address designated as RFU, it is ignored; no response UL is sent.

4.2.4.2 Write/Error Response

A message UL is sent on **LoRaWAN port 101** with the frame format as shown in Figure 4-3.

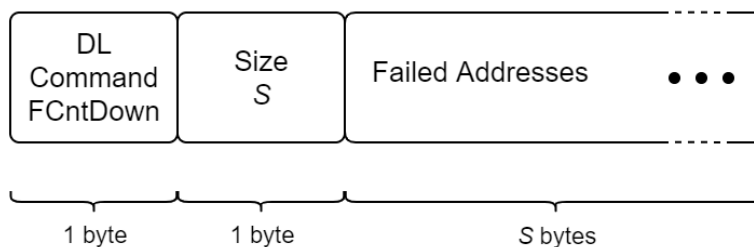


Figure 4-3: The LoRaWAN port 101 Write Response UL Frame Format

⁹ See §4.3.2 for a description of configuration and control commands.

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 [3].
- *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 write command(s) failed.

When a configuration and control DL payload is received, the blocks are processed from MSB to LSB.

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).

If the sensor processes a read or write command block trying to access a register designated as RFU, or a write command block attempting to write an invalid value to an accessible register, the register address is added to the port 101 response UL. If there are other valid read or write command blocks after this in the DL payload, they are not executed, and the corresponding register addresses are not included in the port 101 response. If there were command and control operation blocks present, they are not executed.

4.2.4.3 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.

4.2.5 LoRa Cloud Communications (*LoRaWAN Port 192, 197, and 199 ULS*)

LoRaWAN ports 192, 197, and 199 are used for LoRa Cloud communication messages for geolocation purposes.

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

LoRa Cloud requests such as clock sync and almanac update requests are sent on **LoRaWAN port 199**.

See §6.1.2 for a description of STORK's geolocation cycle report behaviour. See Figure 0-6 and Figure 0-7 in Appendix 1 for a summary of the frame formats.

4.3 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 STORK sensor¹⁰:

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 and almanac updates.

Each DL must be sent on the appropriate downstream port. The DL streams supported by the STORK SW are shown in Table 4-2.

Table 4-2: 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 |

4.3.1 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**.

See §2.1 for more information about DEEP SLEEP.

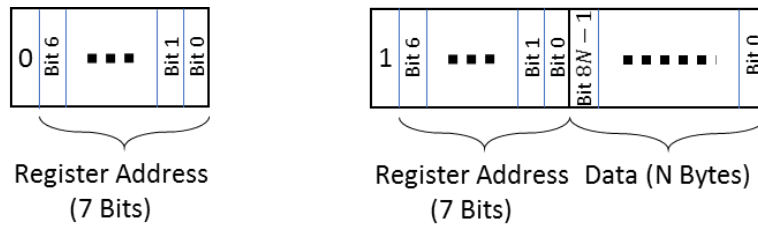
4.3.2 Configuration and Control Commands (LoRaWAN Port 100 DLs)

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 operations¹¹.

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 4-4. 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.

¹⁰ 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].

¹¹ See §4.1 for general information about configuration registers.



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

Figure 4-4: 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 4-4.

- **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.

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 0-3 in Appendix 2. These details are also included in the corresponding function-specific sections:

- LoRaMAC Options | §5.1.2
- Periodic Report Scheduling | §5.2.2
- Battery Management | §5.3.3
- General Command and Control Operations | §5.4.1
- Geolocation and GNSS | §6.1.3
- GNSS Diagnostics | §6.2.3
- BLE Tracker Mode | §7.1.3
- BLE Beacon Mode | §7.2.2
- Toggling BLE Modes | §7.3.1
- Accelerometer | §8
- Ambient Environment Sensing | §9

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

LoRaWAN ports 192 and 199 are used for LoRa Cloud communication messages for geolocation purposes such as status requests and almanac updates. These processes occur according to the specifications of LoRa Cloud [6]. The behaviour is not configurable and therefore outside the scope of this document.

5 Basic Operation

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

- **LoRaMAC Options:** LoRaWAN general parameters and behaviour as defined by the LoRaWAN Specifications [3].
- **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.

5.1 LoRaMAC Options

5.1.1 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 [3], [4]. Refer to these sources for detailed descriptions of these parameters and expected behaviour, as this is outside the scope of this TRM.

5.1.2 Configuration Settings

Table 5-1 shows the MAC configuration registers. In this table, the bit indexing scheme is as shown in Figure 4-1. To access these registers, a command must be formatted and sent according to the details described in §4.3.2.

Table 5-1: 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) <ul style="list-style-type: none"> • 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 | <ul style="list-style-type: none"> • Unconfirmed UL • Public Sync Word • Duty cycle enabled • ADR disabled <p style="text-align: center;">0x 00 06</p> | <pre>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) }</pre> |
| 0x 12 | DR and Tx Power ¹² | 2 B | Access: R/W <ul style="list-style-type: none"> • Bits 8-11: Default DR number • Bits 0-3: Default Tx power number, <i>m</i> • Bits 4-7, 12-15: RFU | <ul style="list-style-type: none"> • DR3 • Tx Power 0 (max power; see Table 5-2) <p style="text-align: center;">0x 03 00</p> | <pre>loramac_dr_tx: { dr_number: <value>, (unsigned/no unit) tx_power_number: <value> (unsigned/no unit) }</pre> |

¹² Tx power number *m* translates to the maximum Tx power, which is a function of the LoRaWAN RF region, minus $2 \times m$ dB [2].

Table 5-2: Default Max Tx Power by Region

| RF Region | Max Tx EIRP ¹³ [dBm] |
|-----------|---------------------------------|
| EU868 | 16 |
| US915 | 30 |
| AS923 | 16 |
| AU915 | 30 |
| IN865 | 30 |
| KR920 | 14 |
| RU864 | 16 |

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.

5.1.2.1 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

¹³ These are Tx power *setpoints* and are the maximum allowable by the LoRaWAN regional parameters specification [2]. The actual Tx power of the sensor is limited by the radio transceiver, which is 15 dBm. Therefore, a setpoint greater than 15 dBm will be equivalent to a setpoint of 15 dBm or the Max Tx EIRP for the region, whichever is lower.

5.2 Periodic Report Scheduling

5.2.1 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:

$$\langle \text{Data Type} \rangle \text{ Reporting Period} = \text{Seconds per Core Tick} \times \text{Ticks per } \langle \text{Data Type} \rangle$$

The available options for periodically reported data types are listed below. That is, $\langle \text{Data Type} \rangle$ can be:

- **Battery:** Remaining capacity [%], remaining lifetime [days], or both. See §5.3 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
 - GNSS raw scan data for LoRa Cloud.
 - GNSS diagnostics information.
 - Discovered Wi-Fi access point MAC addresses and RSSIs [dBm].
 - Discovered BLE device MAC addresses and RSSIs.

2 different update periods can be defined; 1 that is used when the sensor is in the MOBILE state and the other when in STILL. See §8.4 for how motion and stillness are detected.

- **Accelerometer:** Acceleration vector [*g*]. See §8 for accelerometer operation details.
- **Ambient Temperature:** Temperature of the ambient environment [°C]. See §9 for environment sensing details.
- **Ambient Relative Humidity:** RH of the ambient environment [%]. See §9 for environment sensing details.

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

If $\langle \text{Data Type} \rangle \text{ Reporting Period}$ 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* $\langle \text{Data Type} \rangle$ is equal to 0. Therefore, to disable the periodic reporting of a specific data type, set its *Ticks per* $\langle \text{Data Type} \rangle$ to 0.

The default reporting behaviour is:

- 1 battery report per day.
- 1 geolocation update per hour while not moving.
- 1 geolocation update per 15 minutes while moving.

- 1 temperature report per hour.
- 1 RH 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 reporting periods to less than 3.5 min. See §6.1.3.3 for guidelines on best practices for periodic configuration.

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 one thereafter will occur at the expected 24-hour intervals).

5.2.1.1 Anti-Bricking Strategy

As a Class-A LoRaWAN end-device, the sensor can only be receptive to 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*.

STORK has the ability to manually force a UL by magnet tap which cannot be disabled, so it is impossible to *completely* brick a sensor. However, there are use cases in which using a magnet 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 week.

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 §5.2.1 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:

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

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

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

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 $\left\lfloor \frac{604\,800 \text{ s}}{\text{Seconds per Core Tick}} \right\rfloor$.

5.2.2 Configuration Settings

Table 5-3 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 28. In this table, the bit indexing scheme is as shown in Figure 4-1. To access these registers, a command must be formatted and sent according to the details described in §4.3.2.

Table 5-3: 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 | <i>seconds_per_core_tick</i> : <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 | <i>ticks_per_battery</i> : <value> (unsigned/no unit) |
| 0x 22 | Ticks per Geolocation Update in STILLNESS 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 | <i>ticks_per_geolocation_update_stillness</i> : <value> (unsigned/no unit) |

| Address | Value | Size | Description and Options | Default Value | JSON Variable (Type/Unit) |
|---------|--|------|---|--|--|
| 0x 23 | Ticks per Geolocation Update in MOBILITY State | 2 B | Access R/W <ul style="list-style-type: none"> • 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 | <i>ticks_per_geolocation_update_mobility: <value> (unsigned/no unit)</i> |
| 0x 24 | Ticks per Accelerometer | 2 B | Access R/W <ul style="list-style-type: none"> • Ticks between accelerometer vector reports • Acceptable values: 0, 1, 2, ..., 65535 • 0 disables periodic accelerometer vector reports | Periodic reporting disabled 0x 00 00 | <i>ticks_per_accelerometer: <value> (unsigned/no unit)</i> |
| 0x 25 | Ticks per Temperature | 2 B | Access R/W <ul style="list-style-type: none"> • Ticks between ambient temperature reports • Acceptable values: 0, 1, 2, ..., 65535 • 0 disables periodic temperature reports | 60 ticks = 1 hr period 0x 00 3C | <i>ticks_per_ambient_temp: <value> (unsigned/no unit)</i> |
| 0x 26 | Ticks per Relative Humidity | 2 B | Access R/W <ul style="list-style-type: none"> • Ticks between ambient RH reports • Acceptable values: 0, 1, 2, ..., 65535 • 0 disables periodic RH reports | 60 ticks = 1 hr period 0x 00 3C | <i>ticks_per_ambient_rh: <value> (unsigned/no unit)</i> |

5.2.2.1 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

5.3 Battery Management

5.3.1 Operational Description

The STORK 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 remaining battery lifetime is estimated using the past energy consumption rate trends over a timeframe called the *Average Energy Trend Window*. This is a rolling window of configurable size that contains the most recently collected energy consumption rate data. The window size is defined in units of core ticks and the default value is 10 core ticks. In other words, by default, the remaining battery lifetime is estimated based on energy consumption rates over the last 10 core ticks only, which is visualized in Figure 5-1.

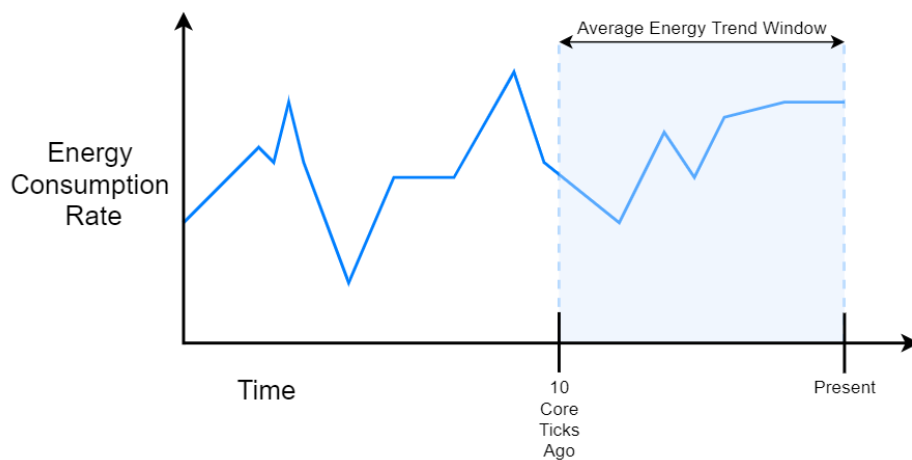


Figure 5-1: Example Visualization of the Default Average Energy Trend Window

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 §5.3.2, 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 average energy trend window over which “steady state” energy consumption occurs before the remaining battery lifetime values stabilize.

5.3.1.1 Resets and Battery Replacement

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

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

5.3.1.2 Battery Passivation

Due to the chemistry of the batteries (LTC), a *passivation layer* can build up internally during periods when the battery has little to no charge flowing out. This layer can prevent high pulse current draws for a few minutes at the time of first-use [7]. As the sensor begins drawing current from the battery, the passivation begins to break down. The longer the dormant state of the battery, the longer it takes to break the passivation layer down.

At the user-level, passivation means that the first time a sensor is woken up or powered on with a new battery, it is possible that there is some ramp-up time required before it can complete the join procedure. Until the device detects that it can get enough current from the battery, it will constantly reset in attempt to break the passivation layer down. If this occurs, the LEDs will go through the normal power-on patterns and begin the join pattern (flashing green) for about 1 s before a reset occurs (i.e., steps 1-4a in §3.1.1).

Some example circumstances which may lead to battery passivation include:

- The battery is replaced with a new one, including new devices from the factory, where the battery may have been unused for more than a month.
- The sensor was in DEEP SLEEP for longer than a month, such as while being in long-term storage or warehouse stock.

5.3.2 UL Report Frame Formats

Battery reports are sent on **LoRaWAN port 10** and have the frame format as shown in Figure 4-2. The specific details for the battery report frame formats are listed in Table 5-4. For the general description of sensor data report formats and behaviour, see §4.2.1.

Table 5-4: 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) | <i>rem_batt_capacity: <value> (unsigned/%)</i> |
| Remaining Battery Lifetime | 0x 00 | 0x BD | 2 B | Days | 1 day / LSb | <i>rem_batt_days: <value> (unsigned/days)</i> |

5.3.2.1 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

- **0x 00 BA 6E**
 - Channel ID = 0x 00, Type ID = 0xBA → battery voltage data report
 - 0x 6E = (110 × 0.01 V) + 2.50 V = 3.60 V

5.3.3 Configuration Settings

All configuration registers that control battery management behaviour are listed in Table 5-5. In this table, the bit indexing scheme is as shown in Figure 4-1. To access these registers, a command must be formatted and sent according to the details described in §4.3.2.

Table 5-5: 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 <ul style="list-style-type: none"> • 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 | <i>seconds_per_core_tick: <value> (unsigned/s)</i> |

| Address | Name | Size | Description and Options | Default Value | JSON Variable (Type/Unit) |
|---------|-----------------------------|------|---|---|---|
| 0x 21 | Ticks per Battery | 2 B | Access R/W <ul style="list-style-type: none"> • Ticks between battery reports • Acceptable values: 1, 2, 3, ..., 65535 • 0: Invalid and ignored | 1440 ticks = 1 day period 0x 05 A0 | <i>ticks_per_battery: <value></i> <i>(unsigned/no unit)</i> |
| 0x 4A | Battery Report Options | 1 B | Access: R/W <ul style="list-style-type: none"> • 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 | <pre> battery_tx: { report_capacity_enabled: <value>, (unsigned/no unit) report_lifetime_enabled: <value> (unsigned/no unit) } </pre> |
| 0x 4B | Average Energy Trend Window | 1 B | Access: R/W <ul style="list-style-type: none"> • Window size over which remaining battery lifetime is estimated [1 core tick/LSB] • Acceptable values: 1, 2, ..., 255 • 0: Invalid and ignored | 10 core ticks 0x 0A | <i>avg_energy_trend_window: <value></i> <i>(unsigned/no unit)</i> |

5.3.3.1 Periodic Reporting Configuration

The battery reporting period can be configured using registers 0x 20 and 0x 21 according to the equation described in §5.2.2. That is:

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

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

5.3.3.2 Operational Configuration

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

The average energy trend window size is configured using register 0x 4B.

5.3.3.3 Guidelines for Best Practice

It is recommended that the average energy trend window be configured in relation to the core tick setting. For example, a large core tick setting and large window will result in a long time for

the remaining battery lifetime to be calculated accurately and will take a long time to respond to changes in energy consumption. A small core tick setting and small window will result in more fluctuations in consecutive battery reports.

The optimal settings may need to be tuned for particular use cases.

5.3.3.4 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

5.4 General Command-and-Control Operations

5.4.1 List of Operations and Register Values

The general command and control operations supported by the STORK 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 5-6 lists the details of the command-and-control registers. In this table, the bit indexing scheme is as shown in Figure 4-1. To access these registers, a command must be formatted and sent according to the details described in the following subsections and in §4.3.2.

Table 5-6: Command & Control Register Details

| Address | Access | Name | Size | Description and Options | JSON Variable (Type/Unit) |
|---------|--------|---------------------|------|--|---|
| 0x 70 | X | Flash Write Command | 2 B | <ul style="list-style-type: none"> • 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: Ignored | <pre>write_to_flash { app_config: <value>, (unsigned/no unit) lora_config: <value>, (unsigned/no unit) restart_sensor: <value> (unsigned/no unit) }</pre> |

| Address | Access | Name | Size | Description and Options | JSON Variable (Type/Unit) |
|---------|--------|---|------|---|--|
| 0x 71 | RO | FW Metadata | 7 B | <ul style="list-style-type: none"> • 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 number¹⁴ | <pre>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) }</pre> |
| 0x 72 | X | Reset Configuration to Factory Defaults | 1 B | <ul style="list-style-type: none"> • 0x 0A: Reset app configuration • 0x B0: Reset LoRaMAC configuration • 0x BA: Reset both App and LoRaMAC configurations • Any other value: Invalid and ignored | <pre>config_factory_reset { app_config: <value>, (unsigned/no unit) loramac_config: <value> (unsigned/no unit) }</pre> |
| 0x 73 | RO | BLE Metadata | 6 B | <ul style="list-style-type: none"> • 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 | <pre>ble_metadata { stack_ver_major: <value>, (unsigned/no unit) stack_ver_minor: <value>, (unsigned/no unit) stack_ver_revision: <value>, (unsigned/no unit) }</pre> |

¹⁴ Defined by Table 5-7.

5.4.2 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 4-4. 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 5-6. 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 §5.4.3. When this option is not selected, the sensor will send a write response (as described in §4.2.4) after receiving the flash write command.

5.4.3 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 §5.4.2 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 rebooting¹⁵.

5.4.4 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 4-4. 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 first 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 5-2, which is shown using the example FW v1.0.15 (value 0x 01 00 0F).

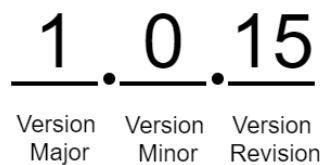


Figure 5-2: Example FW Version Format

- Bits 8 to 31 of the value contain the LoRa Basics modem version numbers. The format is the same as shown in Figure 5-2. 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 5-7.

Table 5-7: LoRaMAC Regions and Region Numbers

| LoRaMAC Region | Region Number |
|----------------|---------------|
| EU868 | 0 |
| US915 | 1 |

¹⁵ 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.

| LoRaMAC Region | Region Number |
|----------------|---------------|
| AS923 | 2 |
| AU915 | 3 |
| IN865 | 4 |
| KR920 | 6 |
| RU864 | 7 |

- For BLE metadata:
 - The first 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 5-2.

5.4.5 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 4-4. 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 5-6. 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 rebooting¹⁶.

¹⁶ 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.

6 Geolocation Operation

The primary purpose of the STORK is to track assets indoors and outdoors using a combination of location-tracking technologies:

- **Low-Power GNSS:** Outdoor tracking using satellite geolocation.
- **Wi-Fi Sniffing:** Outdoor and/or indoor tracking using Wi-Fi access point geolocation.
- **BLE Tracking:** Indoor tracking using BLE beacon network localization.

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 to calculate the estimated sensor location. As such, the STORK is meant to be a component in an end-to-end asset tracking solution as shown in Figure 1-1.¹⁷ Due to this edge-based location resolving technique, the battery life of the device increases.

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

¹⁷ **NOTE:** The STORK only reports *raw* scan results and cannot resolve its own location alone. An application server must be set up, integrated with the NS, and enabled to use the proper cloud location services to resolve the location. For information about setting up the rest of the end-to-end solution components shown in Figure 1-1, refer to the TEKTELIC support portal *Knowledge Base* articles [2].

6.1 Scan Cycle and Resolving GNSS, Wi-Fi, and BLE Locations

6.1.1 Operational Description

The STORK conducts 1 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 6-1. By default, the geolocation update period is shorter when the sensor is in motion and longer when the sensor is still¹⁸. These periods are configurable as described in §6.1.3.

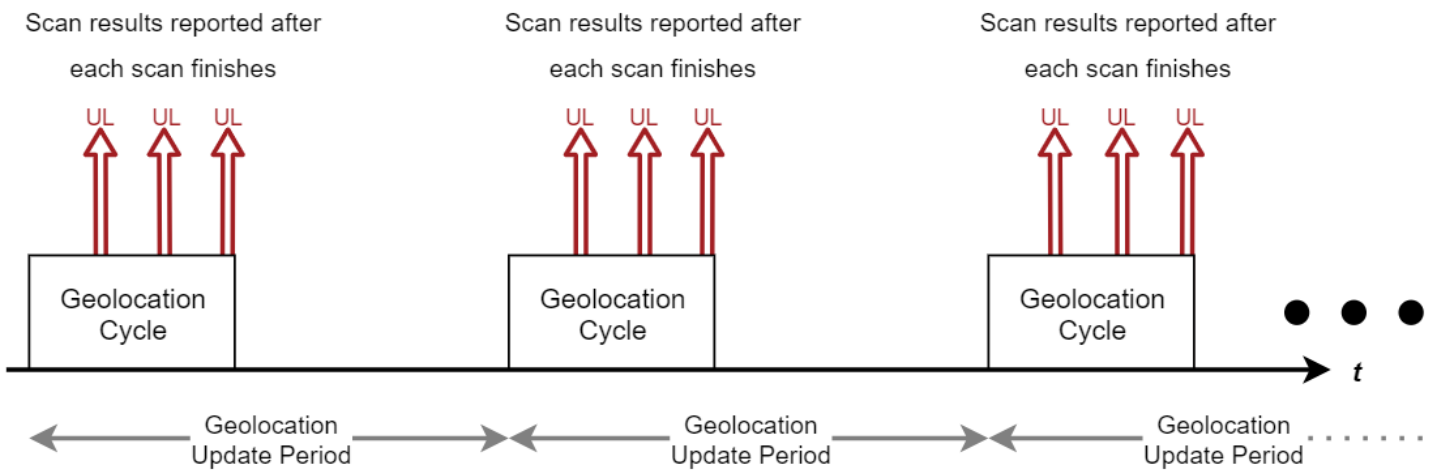


Figure 6-1: Periodic Geolocation Cycles and ULs

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 begins¹⁹.

The duration of each geolocation cycle may vary from 10s 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 scans may not complete, and data may be lost. If GNSS scanning is enabled, it is not recommended to set the geolocation update period to less than 3.5 min. If BLE scanning is enabled, it is not recommended to set the geolocation update to less than 20 s. (see §6.1.3.3).

The supported scan type options and behaviours are summarized in Table 7-1.

¹⁸ See §8.4 for how the accelerometer detects motion to help change the geolocation update period.

¹⁹ 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 6-1: Supported Geolocation Scan Technologies

| Technology | Function | Results Format | Scan Failure Behaviour | Configurable Options |
|------------|---|--|---|--|
| GNSS | 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: 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. | <ul style="list-style-type: none"> • Clock sync parameters • Almanac update parameters • Assist coordinates • Satellite constellation (GPS/BeiDou/both) • Scan mode (mobile/static) |
| 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: 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 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. | <ul style="list-style-type: none"> • 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:

Table 6-2: Scan Order Logic Options

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

6.1.1.1 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 6-3.

Table 6-3: Geolocation Strategies

| Strategy Description | Scan Order Logic | Number of Defined Scans | | |
|--|------------------|-------------------------|----|----|
| | | 3 | 2 | 1 |
| FALLBACK <ul style="list-style-type: none"> • 1st priority scan always done. • Fallback to other scan(s) upon failure. • End cycle upon successful scan. | A | #1 | #2 | #7 |
| 1 BACKUP <ul style="list-style-type: none"> • 1st and 2nd priority scans always done. • 3rd scan if both 1st and 2nd scans failed. | B | #3 | #6 | #7 |
| 2 BACKUPS <ul style="list-style-type: none"> • 1st priority scan always done. • 2nd and 3rd scans done if 1st scan failed. | C | #4 | #2 | #7 |
| ALL SCANS <ul style="list-style-type: none"> • All defined scans always done. | D | #5 | #6 | #7 |

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

- Delivery vehicle tracking: FALLBACK with (1) GNSS, (2) Wi-Fi, (3) BLE
Likely to be outside for most of the time, so GNSS is likely to succeed most of the time. Wi-Fi is next most likely, then BLE.
- Pallet tracking in a multi-building site: 2 BACKUP with (1) BLE, (2) Wi-Fi, (3) GNSS
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 GNSS, Wi-Fi, BLE. The operational flow of this strategy is depicted in Figure 6-2. All other strategy flow depictions are shown in Appendix 3.

Geolocation Strategy 1 (Default) Fallback, All Scans Defined

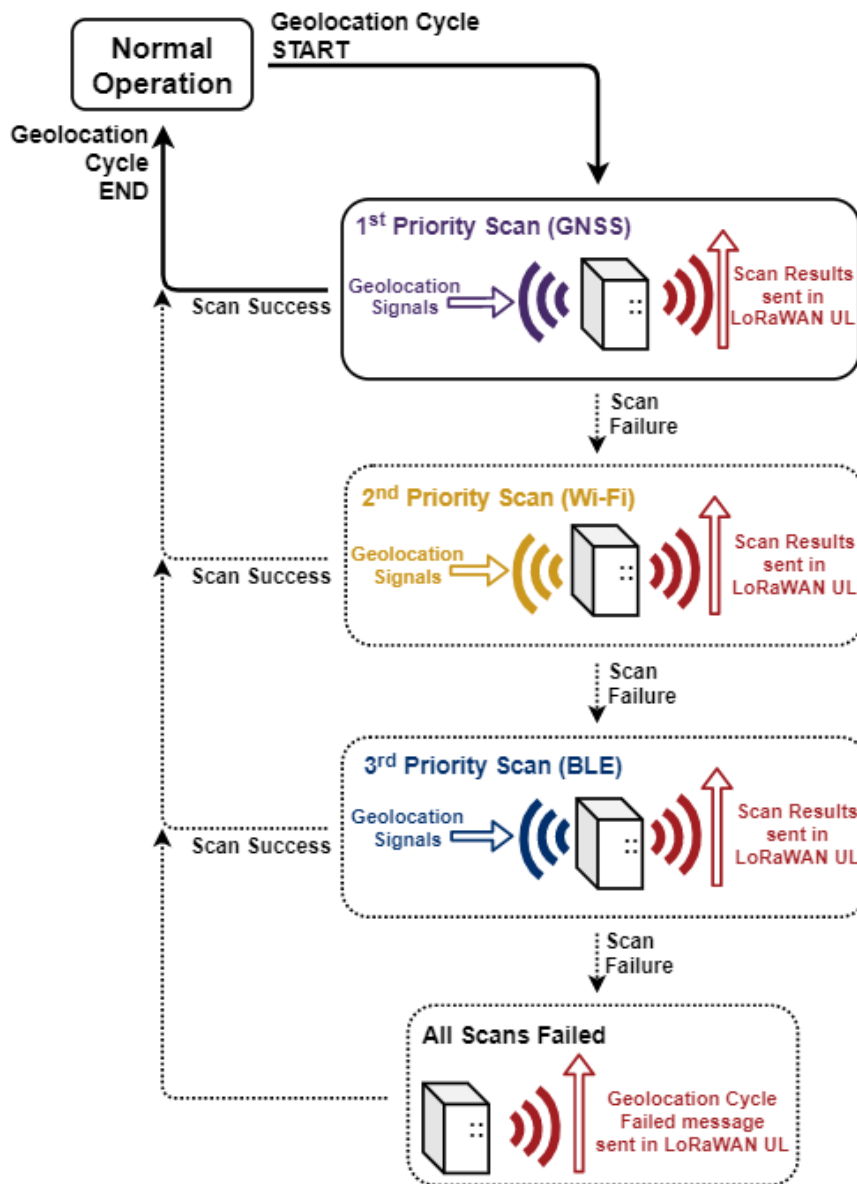


Figure 6-2: Default Geolocation Strategy Cycle Flow

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

6.1.1.2 GNSS and Wi-Fi Operation with LoRa Cloud Resolvers

The GNSS 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 the STORK and LoRa Cloud server to transfer all the information needed for the positions to be resolvable.

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

- Valid clock synchronization: The internal time of the sensor must be synchronized periodically. The sync interval, sync expiration timeout, and sync service option are all configurable.
- Valid almanac: The almanac in the sensor must be kept up-to-date. The update check period and update request UL interval are configurable.
- 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.

Other user-configurable options for GNSS scanning include the choice of satellite constellation (GPS, BeiDou, or both) and mobile or static scanning. The Wi-Fi scanning has no configurable options.

NOTE: The STORK's default configuration is chosen for the average user, and changing GNSS scan parameters from default is only recommended for advanced users. For detailed descriptions of these parameters and other LoRa Cloud details, refer to the Semtech LR1110 documentation [6].

6.1.1.3 BLE Operation with LOCUS and the GRB

The 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* articles [2]. For a description of BLE scan behaviour, see §7.1.1.

6.1.2 UL Report Frame Formats

GNSS scan results are sent on **LoRaWAN port 192** and have the frame format shown in Figure 6-3. Wi-Fi scan results are sent on **LoRaWAN port 197** and have the frame format shown in Figure 6-4. 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 [6].

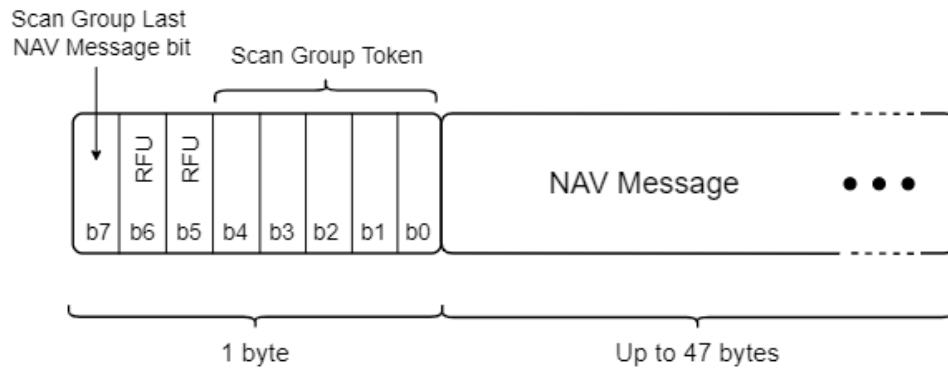


Figure 6-3: The GNSS Scan Results UL Frame Format

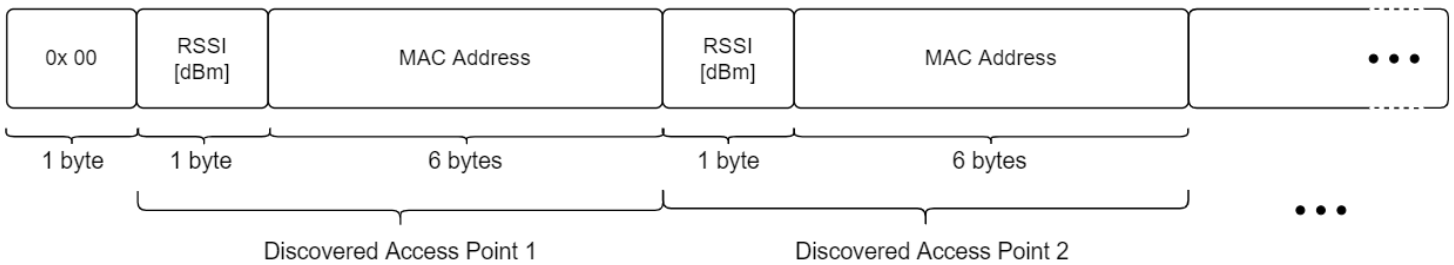


Figure 6-4: The Wi-Fi Scan Results UL Frame Format

BLE scan results are sent on **LoRaWAN port 25**. For a description of these report formats, see §7.1.2.

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 4-2. The specific details are listed in Table 6-4. For the general description of sensor data report formats and behaviour, see §4.2.1.

Table 6-4: 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 | <ul style="list-style-type: none"> • Bits 0-1: GNSS Scan <ul style="list-style-type: none"> ○ 00: Scan failed ○ 11: Scan successful or scan not done • Bit 2: Wi-Fi scan <ul style="list-style-type: none"> ○ 0: Scan failed ○ 1: Scan successful or scan not done • Bit 3: BLE scan <ul style="list-style-type: none"> ○ 0: Scan failed ○ 1: Scan successful or scan not done • Bit 4: LoRaWAN duty cycle <ul style="list-style-type: none"> ○ 0: GNSS and/or Wi-Fi scan results dropped due to duty cycle restrictions ○ 1: No duty cycle restriction impacts • Bits 5-7: all 0 (RFU) | <pre>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) }</pre> |

6.1.2.1 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 10**
 - 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).

6.1.3 Configuration Settings

Table 6-5 shows the list of configuration registers which affect geolocation and GNSS behaviour. In this table, the bit indexing scheme is as shown in Figure 4-1. To access these registers, a

command must be formatted and sent according to the details described in §4.3.2. For BLE configuration, see §7.1.3.

Table 6-5: 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 <ul style="list-style-type: none"> • 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 | <i>seconds_per_core_tick: <value></i> <i>(unsigned/s)</i> |
| 0x 22 | Ticks per Geolocation Update in STILL State | 2 B | Access R/W <ul style="list-style-type: none"> • 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 | <i>ticks_per_geolocation_update_stillness: <value></i> <i>(unsigned/no unit)</i> |
| 0x 23 | Ticks per Geolocation Update in MOBILE State | 2 B | Access R/W <ul style="list-style-type: none"> • 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 | <i>ticks_per_geolocation_update_mobility: <value></i> <i>(unsigned/no unit)</i> |

| Address | Name | Size | Description and Options | Default Value | JSON Variable (Type/Unit) |
|---------|-------------------------------|------|--|--|--|
| 0x 30 | Geolocation Strategy | 1 B | <p>Access: R/W</p> <ul style="list-style-type: none"> • Bits 0-1: 1st priority scan <ul style="list-style-type: none"> ○ 01: BLE ○ 10: WIFI ○ 11: GNSS ○ 00: Invalid and ignored • Bits 2-3: 2nd priority scan <ul style="list-style-type: none"> ○ 00: Not defined ○ 01: BLE ○ 10: WIFI ○ 11: GNSS • Bits 4-5: 3rd priority scan <ul style="list-style-type: none"> ○ 00: Not defined ○ 01: BLE ○ 10: WIFI ○ 11: GNSS • Bits 6-7: Scan order logic option (see Table 6-2) <ul style="list-style-type: none"> ○ 00: A ○ 01: B ○ 10: C ○ 11: D • Restrictions: <ul style="list-style-type: none"> ○ 2nd scan must be defined to set 3rd scan ○ Scan types can only be defined once | <ul style="list-style-type: none"> • 1st priority scan: GNSS • 2nd priority scan: Wi-Fi • 3rd priority scan: BLE • Scan order logic option A <p>0b 00 01 10 11 or 0x 1B</p> | <pre>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) }</pre> |
| 0x 33 | Clock Sync Configuration | 1 B | <p>Access: R/W</p> <ul style="list-style-type: none"> • Bits 0-3: clock sync interval m, [1 day/LSb] <ul style="list-style-type: none"> ○ Acceptable values: $0 \leq m \leq 15$ ○ 0: Disables clock sync • Bits 4-6: Invalid clock delay multiplier, n <ul style="list-style-type: none"> ○ Acceptable values: $1 \leq n \leq 7$ ○ 0: Invalid and ignored • Bit 7: Clock sync service <ul style="list-style-type: none"> ○ 0: LoRaMAC clock sync ○ 1: LoRa Cloud clock sync | <ul style="list-style-type: none"> • $m = 7$ days = 1 week • $n = 4 \rightarrow 4$ weeks • LoRa Cloud clock sync service <p>0x C7</p> | <pre>clock_sync: { interval: <value>, (unsigned/days) invalid_delay_multiplier: <value>, (unsigned/no unit) service: <value>, (unsigned/no unit) }</pre> |
| 0x 34 | Almanac Update Request Period | 2 B | <p>Access: R/W</p> <ul style="list-style-type: none"> • Interval between sending almanac update requests ULs [1 s/LSb] • Acceptable values: 10, 11, 12, ..., 65535 • 0, 1, 2, ..., 9: Invalid and ignored | <p>30 seconds</p> <p>0x 00 1E</p> | <pre>almanac_update_request_peri od: <value>, (unsigned/s)</pre> |

| Address | Name | Size | Description and Options | Default Value | JSON Variable (Type/Unit) |
|---------|-------------------------------------|------|--|---|---|
| 0x 35 | Almanac Update Check Period | 1 B | Access: R/W <ul style="list-style-type: none"> Interval between sending almanac update check ULs [1 day/LSb] Acceptable values: 0, 1, 2, ..., 90 Other values: invalid and ignored 0: Disables almanac update checking | 1 day 0x 01 | <i>almanac_update_check_period</i> : <value>, (unsigned/s) |
| 0x 36 | Assist Coordinates | 8 B | Access: R/W <ul style="list-style-type: none"> Bit 0: <ul style="list-style-type: none"> 0/1: disable/enable assist coordinates Bits 1-15: RFU Bits 16-39: Longitude y [(180°/2²³)/LSb ≈ 0.000002°/LSb] <ul style="list-style-type: none"> Acceptable values: -180 ≤ y ≤ 180 Bits 40-63: Latitude x [(90°/2²³)/LSb ≈ 0.000001°/LSb] <ul style="list-style-type: none"> Acceptable values: -90 ≤ x ≤ 90 | <ul style="list-style-type: none"> Assist coordinates disabled x = 0° y = 0° 0x 00 00 00 00 00 00 00 00 | <i>assist_coordinates</i> : { <i>latitude</i> : <value>, (signed/°) <i>longitude</i> : <value>, (signed/°) <i>enabled</i> : <value>, (unsigned/no unit) } |
| 0x 37 | GNSS Satellite Constellation Option | 1 B | Access: R/W <ul style="list-style-type: none"> 0x 00: GPS 0x 01: BeiDou 0x 02: GPS and BeiDou Other values: invalid and ignored | GPS and BeiDou 0x 02 | <i>gnss_constellation_option</i> : <value> (unsigned, no unit) |
| 0x 38 | Default GNSS Scan Mode | 1 B | Access: R/W <ul style="list-style-type: none"> Default GNSS scan mode when the accelerometer is not enabled <ul style="list-style-type: none"> 0x 00: Static scanning mode 0x 01: Mobile scanning mode Other values: invalid and ignored | Mobile scanning mode 0x 01 | <i>default_gnss_scan_mode</i> : <value> (unsigned, no unit) |

6.1.3.1 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 §5.2.2. That is:

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

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

The *Accelerometer Assist* feature (described in §8.4) allows the STORK to determine whether to use the STILLNESS or MOBILE geolocation update period depending on the motion state of the device. By default, the STORK conducts a geolocation update cycle once every hour when still and once every 15 min while in motion.

As illustrated in Figure 6-1, 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 of to 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.

If GNSS scanning is enabled, it is not recommended that the update periods are set to less than 3.5 min. If BLE scanning is enabled, it is not recommended that the update periods are set to less than 30 s. See §6.1.3.3 for guidelines about configuring and best practices.

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

6.1.3.2 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.

Registers 0x 33 through 0x 38 control the advanced GNSS settings. The default configuration settings for these registers are chosen for the average user, and changing scan settings from default is only recommended for advanced users. For detailed descriptions of these parameters and other LoRa Cloud details, refer to the Semtech LR1110 documentation [6].

6.1.3.3 Configuration Guidelines and Best Practices

As a class-A LoRaWAN end-device, the STORK 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 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 §7.1.
- The report time 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 periods can be configured to be as short as 30 s, it is not recommended to set the geolocation update periods to less than 3.5 min. Setting the periods to less than 3.5 min may result in getting messages less often than expected.

6.1.3.4 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 = GNSS
 - 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

6.2 GNSS Diagnostic Information

6.2.1 Operational Description

Following the conclusion of a GNSS scan, the user can choose which, if any, diagnostic information is reported in a LoRaWAN UL.

If GNSS scans are defined in the geolocation strategy, following either a successful or failed scan, the diagnostics report will be sent in an additional UL after any scan results are sent to LoRa Cloud. The next scan, if defined, will not begin until after the diagnostics report is sent.

Available diagnostics value options to report are:

- *Number of visible satellites*: total number of satellites detected during the GNSS scan. Maximum is 10.
- *Average satellite SNR*: the average signal-to-noise ratio of all signals detected during the GNSS scan, measured in dB. If no satellites were visible, a value of 0x 00 00 is transmitted.
- *Minimum and maximum satellite SNR*: the smallest and largest signal-to-noise ratios of all signals detected in the GNSS scan, measured in dB. If no satellites were visible, a value of 0x 00 00 is transmitted.

6.2.2 UL Report Frame Formats

The specific details for the diagnostic report frame formats are listed in Table 6-6. For the general description of sensor data report formats and behaviour, see §4.2.1.

Table 6-6: UL Frame Formats for GNSS Diagnostic Information

| Information Type | Channel ID | Type ID | Size | Data Type | Data Format | JSON Variable (Type/Unit) |
|-----------------------------------|------------|---------|------|--------------------|---|--|
| Number of Visible Satellites | 0x 0D | 0x 3C | 1 B | Integer (unsigned) | <ul style="list-style-type: none"> • Bits 7-0: Number of satellites detected | <i>num_satellites</i> : <value> (unsigned/no unit) |
| Average Satellite SNR | 0x 0D | 0x 64 | 2 B | Generic (signed) | <ul style="list-style-type: none"> • Bits 15-0: Average SNR of all satellites [0.1 dB/LSb], signed • 0x 00 00 = No satellites visible for calculating average | <i>avg_satellite_snr</i> : <value> (signed/dB) |
| Minimum and Maximum Satellite SNR | 0x 0D | 0x 63 | 4 B | Generic (signed) | <ul style="list-style-type: none"> • Bits 15-0: Minimum SNR of all satellites [0.1 dB/LSb], signed • Bits 31-16: Maximum SNR of all satellites [0.1 dB/LSb], signed • 0x 00 00 00 00 = No satellites visible for calculating average | <i>min_max_satellite_snr</i> : { <i>min</i> : <value>, (signed/dB) <i>maxi</i> : <value>, (signed/dB) <i>ble</i> : <value>, (unsigned/no unit) } |

6.2.2.1 Example UL Payloads

- **0x 0D 3C 06**
 - 0x 0D (channel ID), 0x 3C (type ID) → number of visible satellites
 - 0x 06 → 6 satellites

- **0x 0D 64 FE 79**
 - 0x 0D (channel ID), 0x 64 (type ID) → average satellite SNR
 - 0x FE 79 = $-391 \times 0.1 \text{ dB} = -39.1 \text{ dB}$

6.2.3 Configuration Settings

Table 6-7 shows the configuration register which controls which, if any, GNSS diagnostic information is reported. In this table, the bit indexing scheme is as shown in Figure 4-1. To access these registers, a command must be formatted and sent according to the details described in §4.3.2.

Table 6-7: Geolocation Configuration Registers

| Address | Name | Size | Description and Options | Default Value | JSON Variable (Type/Unit) |
|---------|------------------------------|------|--|---|--|
| 0x 32 | GNSS Diagnostics Value to Tx | 1 B | Access: R/W • Bit 0: 0/1 = Number of Visible Satellites report disabled/enabled • Bit 1: 0/1 = Average Satellite SNR report disabled/enabled • Bit 6: 0/1 = Max and min satellite SNR report disabled/enabled • Bits 2-5, 7: RFU | No diagnostics reported 0x 00 | <pre>gnss_diagnostics_tx { num_satellites: <value>, (unsigned/no unit) avg_satellite_snr: <value>, (unsigned/no unit) min_max_satellite_snr: <value>, (unsigned/no unit) }</pre> |

6.2.3.1 Example DL Payloads

- Enable all GNSS diagnostics to be reported after every GNSS scan:
 - DL payload: **0x B2 43**
 - Register 0x 32 with bit 7 set to 1 = 0x B2
 - Value bits 0, 1, and 6 set to 1 = 0x 43

- Enable only number of visible satellites to be reported after every GNSS scan:
 - DL payload: **0x B2 01**
 - Register 0x 32 with bit 7 set to 1 = 0x B2

- Value bit 1 set to 1 = 0x 01

7 BLE Operation

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

- **Tracker Mode (default):** The sensor conducts geolocation tracking as described in §6. With respect to BLE, if BLE scans are defined (enabled) in the geolocation scan cycle, nearby detected BLE peripherals 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 [8].

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.

7.1 Tracker Mode (BLE Rx)

7.1.1 Operational Description

The default mode of the sensor is tracker mode.

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 §6.1.1.

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 [4].

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

7.1.1.1 Scanning Scheme

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

As illustrated in Figure 7-1, 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.

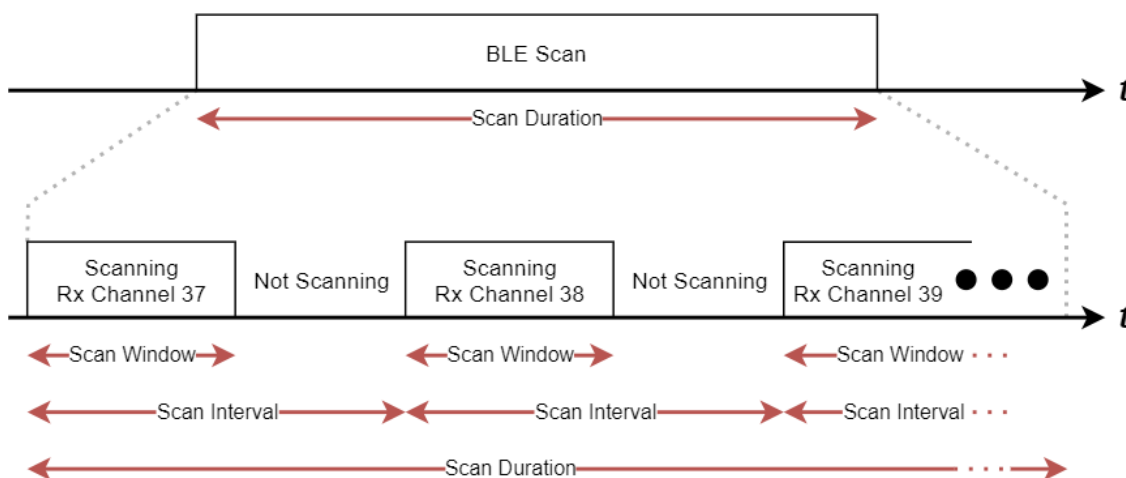


Figure 7-1: The BLE Scan Scheme

Also illustrated in Figure 7-1, the 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.

7.1.1.2 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.

7.1.1.3 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^{20} . 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.

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:

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

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 §7.1.2 for more details on reporting.

²⁰ TEKTELIC's OUI is 64:7F:DA.

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.

7.1.2 UL Report Frame Formats

Discovered BLE devices are reported on **LoRaWAN port 25**. As described in §7.1.1.3, 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].

7.1.2.1 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 7-2. Basic reporting is the default behaviour.

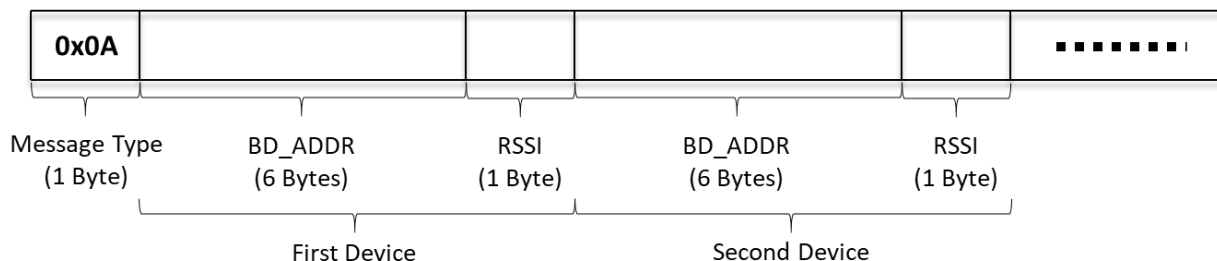


Figure 7-2: The BLE Report UL Payload Format for Basic Reporting

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 §7.1.1.2).

7.1.2.2 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_{ADDRS} are included in the report. The UL payload formats are shown in Figure 7-3.

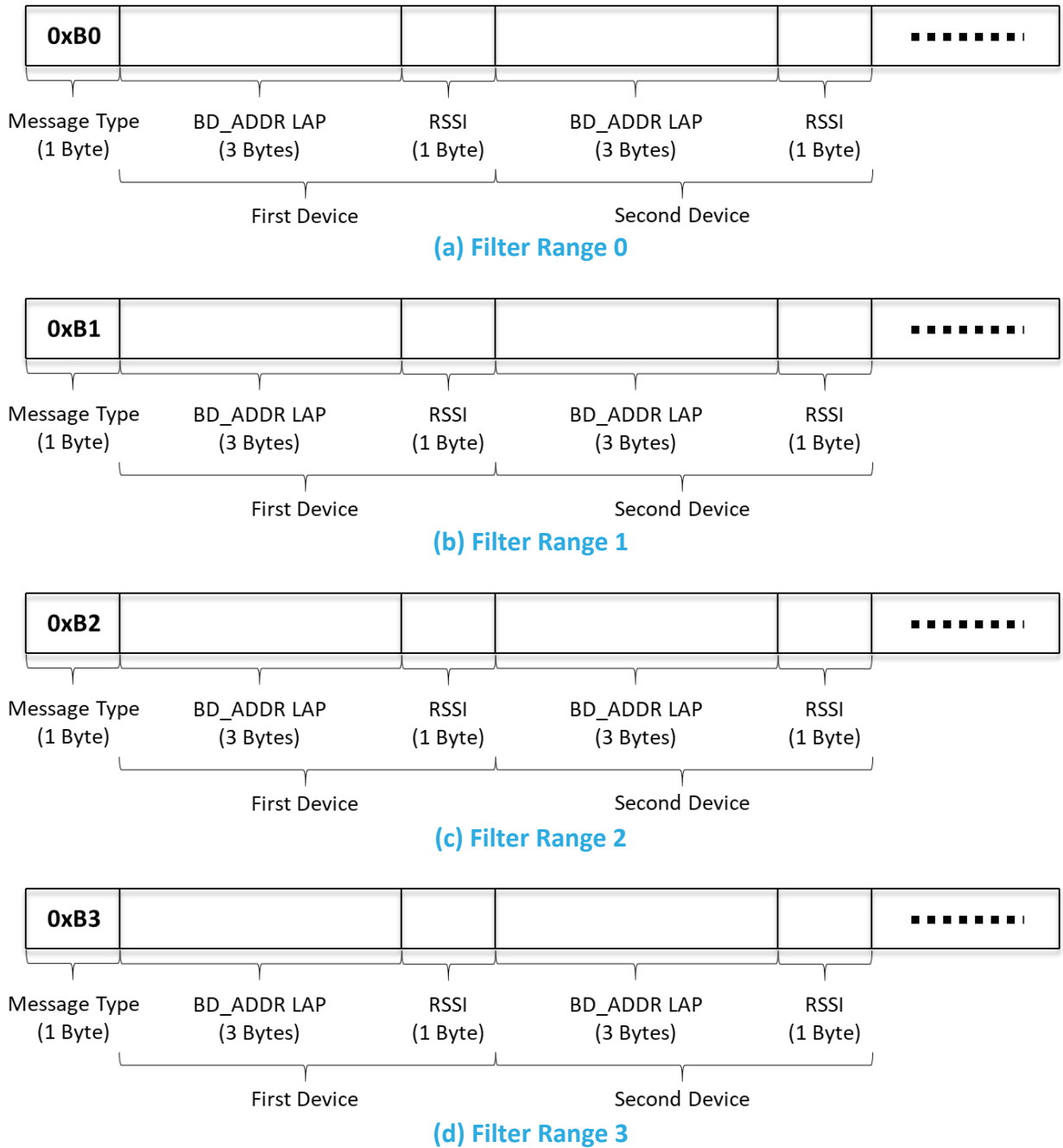


Figure 7-3: BLE Report UL Payload Formats for Filtered Reporting

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 §7.1.1.3 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 §7.1.1.2).

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.

7.1.2.3 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

7.1.3 Configuration Settings

Table 7-1 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 4-1. To access these registers, a command must be formatted and sent according to the details described in §4.3.2. For configuration settings of the geolocation cycle and GNSS scan parameters, see §6.1.3.

Table 7-1: 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 • Bit 7: 0/1 = Averaging mode off/on | • Up to 8 reported devices • Averaging mode on 0x 88 | <pre>ble_mode: { num_reported_devices: <value>, (unsigned/no unit) averaging_mode: <value> (unsigned/no unit) }</pre> |

| Address | Value | Size | Description and Options | Default Value | JSON Variable (Type/Unit) |
|---------|-------------------|------|--|--|--|
| 0x 51 | BLE Scan Duration | 2 B | Access: R/W <ul style="list-style-type: none"> Bits 0-7: <ul style="list-style-type: none"> Scan duration [1 s/LSb] Acceptable values: 1, 2, ..., 10 0: Invalid and ignored Bits 8-15: <ul style="list-style-type: none"> RFU | 3 s 0x 00 03 | <pre>ble_scan_duration: { periodic: <value>, (unsigned/no unit) event-based: <value>, (unsigned/no unit) }</pre> |
| 0x 52 | BLE Scan Interval | 2 B | Access: R/W <ul style="list-style-type: none"> Scan interval [1 ms/LSb] Acceptable values: <ul style="list-style-type: none"> “Scan Window”, ..., 10 000 Other values: <ul style="list-style-type: none"> Invalid and ignored | 30 ms 0x 00 1E | <pre>ble_scan_interval: <value> (unsigned/sec)</pre> |
| 0x 53 | BLE Scan Window | 2 B | Access: R/W <ul style="list-style-type: none"> Scan window [1 ms/LSb] Acceptable values: <ul style="list-style-type: none"> 3, ..., “Scan Interval” Other values: <ul style="list-style-type: none"> Invalid and ignored | 30 ms 0x 00 1E | <pre>ble_scan_window: <value> (unsigned/sec)</pre> |
| 0x 54 | Filter Range 0 | 9 B | Access: R/W <ul style="list-style-type: none"> Range 0 for filtered BD_{ADDRS} $B_0:B_1:B_2:B_3:B_4:B_5$ to $B_0:B_1:B_2:B_6:B_7:B_8$ <ul style="list-style-type: none"> 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 | <pre>filter_range_0: { oui: <value>, (unsigned/no unit) lap_start: <value>, (unsigned/no unit) lap_end: <value> (unsigned/no unit) }</pre> |
| 0x 55 | Filter Range 1 | 9 B | Access: R/W <ul style="list-style-type: none"> Range 1 for filtered BD_{ADDRS} $B_0:B_1:B_2:B_3:B_4:B_5$ to $B_0:B_1:B_2:B_6:B_7:B_8$ <ul style="list-style-type: none"> 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 | <pre>filter_range_1: { oui: <value>, (unsigned/no unit) lap_start: <value>, (unsigned/no unit) lap_end: <value> (unsigned/no unit) }</pre> |
| 0x 56 | Filter Range 2 | 9 B | Access: R/W <ul style="list-style-type: none"> Range 2 for filtered BD_{ADDRS} $B_0:B_1:B_2:B_3:B_4:B_5$ to $B_0:B_1:B_2:B_6:B_7:B_8$ <ul style="list-style-type: none"> 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 | <pre>filter_range_2: { oui: <value>, (unsigned/no unit) lap_start: <value>, (unsigned/no unit) lap_end: <value> (unsigned/no unit) }</pre> |

| Address | Value | Size | Description and Options | Default Value | JSON Variable (Type/Unit) |
|---------|----------------|------|--|--|--|
| 0x 57 | Filter Range 3 | 9 B | Access: R/W <ul style="list-style-type: none"> • Range 3 for filtered BD_{ADDRS} • $B_0:B_1:B_2:B_3:B_4:B_5$ to $B_0:B_1:B_2:B_6:B_7:B_8$ <ul style="list-style-type: none"> ▪ 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 | <pre>filter_range_3: { oui: <value>, (unsigned/no unit) lap_start: <value>, (unsigned/no unit) lap_end: <value> (unsigned/no unit) }</pre> |

7.1.3.1 Periodic Scanning and Reporting Configuration

Since the BLE scan is one of the 3 supported geolocation technologies, BLE scans occur as part of the geolocation cycle and according to the geolocation strategy described in §6.1.

7.1.3.2 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 §7.1.1.2).
- *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.

7.1.3.3 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

7.2 Beacon Mode (BLE Tx)

7.2.1 Operational Description

The STORK 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 §7.3.

When in beacon mode, the BLE operates in Tx only, and all geolocation scans are disabled. The STORK sends out periodic BLE *advertisements* which are small packets of data. These packets are discoverable by other STORKs 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-case²¹. 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.

7.2.1.1 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 7-4. It is user-configurable in units of [ms].

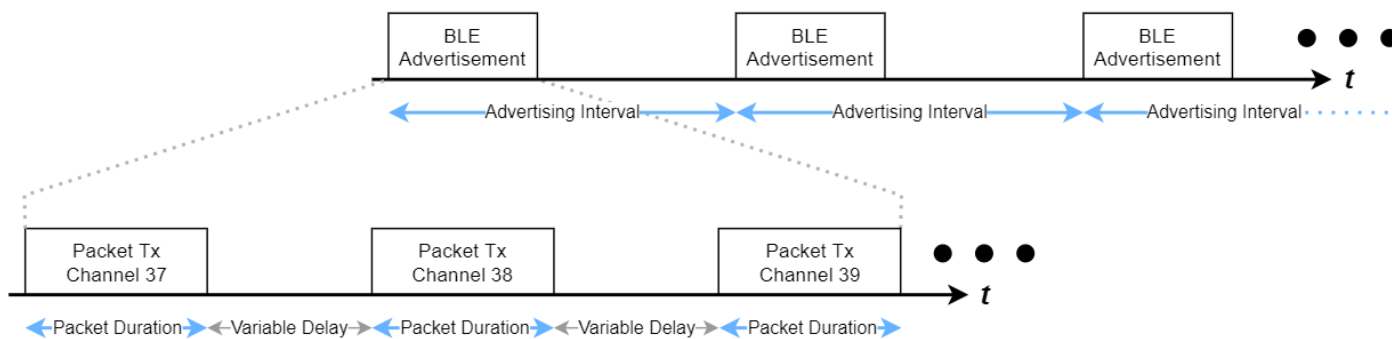


Figure 7-4: The BLE Advertisement Scheme

²¹ The standard beacon is a stationary device mounted on a wall that periodically broadcasts BLE advertisements.

Figure 7-4 also shows that each single BLE advertisement comprises 3 individual packet transmissions, sent one after another on BLE channels 37, 38, and 39 [8]. 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 §7.2.1.2). 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.

7.2.1.2 Advertisement Packet Formats

The BLE advertising packet formatting supports 3 major BLE standards: iBeacon, Eddystone UID, and Eddystone TLM. By default, only iBeacon is enabled. Figure 7-5 shows the frame breakdown of each of these packet formats.

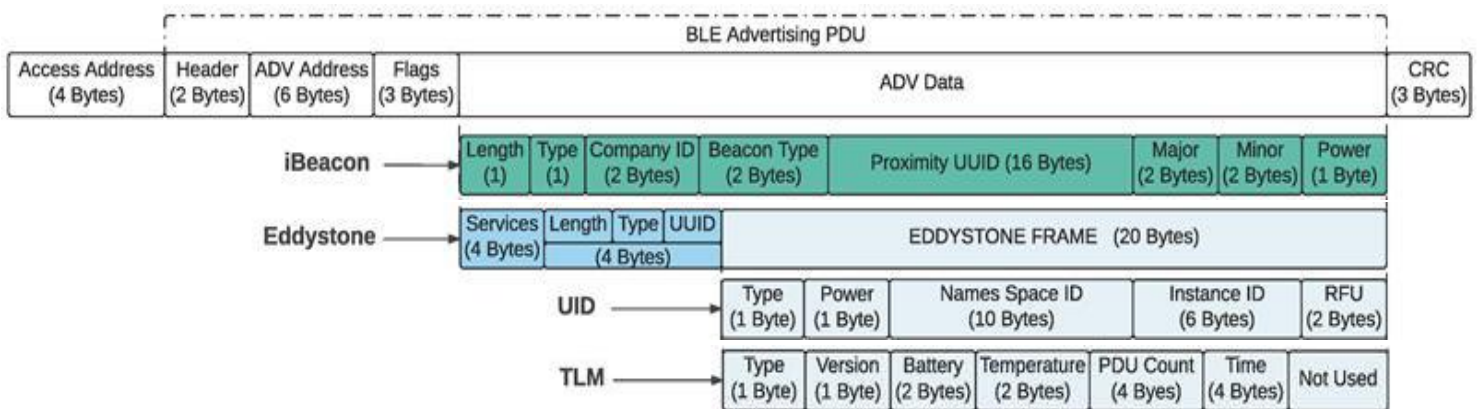


Figure 7-5: Supported Standard BLE Beacon Advertisement Packet Formats

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 5.2 Core Specification [8].

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 100 ms. In this case, at 100 ms, 3 iBeacon packets are transmitted, one on each channel. At 200 ms, 3 Eddystone UID packets are transmitted. At 300 ms, 3 Eddystone TLM packets are transmitted. At 400 ms, 3 iBeacon packets are transmitted. Etc.

7.2.2 Configuration Settings

Table 7-2 shows the list of configuration registers which affect BLE Tx behaviour. In this table, the bit indexing scheme is as shown in Figure 4-1. To access these registers, a command must be formatted and sent according to the details described in §4.3.2.

Table 7-2: BLE Advertising Configuration

| Address | Value | Size | Description and Options | Default Value ²² | 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 | <i>advertising_enabled: <value> (unsigned/no unit)</i> |
| 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 | <i>min_advertising_interval: <value> (unsigned/ms)</i> |
| 0x 5B | BLE Tx Advertising Power | 1 B | Access: R/W • BLE Tx Power [dBm] <ul style="list-style-type: none"> ▪ 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 | <i>tx_advertising_power: <value> (unsigned/no unit)</i> |

²² 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 §7.3. For a summary of all register default values in both tracker and beacon mode, see Table 0-4 in Appendix 2.

| Address | Value | Size | Description and Options | Default Value ²² | JSON Variable (Type/Unit) |
|---------|---------------------------------|------|---|---|---|
| 0x 5C | BLE Advertisement Packet Format | 1 B | Access: R/W <ul style="list-style-type: none"> • 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 | <ul style="list-style-type: none"> • iBeacon enabled • Eddystone UID disabled • Eddystone TLM disabled <p style="text-align: center;">0x 01</p> | <pre> advertising_packet_format: { ibeacon: <value>, (unsigned/no unit) eddystone_uid: <value>, (unsigned/no unit) eddystone_tlm: <value> (unsigned/no unit) } </pre> |
| 0x 5F | BLE MAC Address | 6 B | Access: RO <ul style="list-style-type: none"> • The 6-Byte BLE Device MAC address, BD_{ADDR}, of the sensor. | Unique for every sensor | <pre> mac_address: <value> (unsigned/no unit) </pre> |

7.2.2.1 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.

7.2.2.2 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 §7.1.2.2).

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 Section 7.3), 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 §4.2.4).

7.2.2.3 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

7.3 Toggling Tracker Mode ↔ Beacon Mode

7.3.1 Toggling Procedure and Commands

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

- **Tracker mode:** BLE Rx only, see §7.1 for detailed operation descriptions.
- **Beacon mode:** BLE Tx only, see §7.1.3.3 for detailed operation descriptions.

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 §4.3.2. Table 7-3 shows the details and values for register 0x 0A. In this table, the bit indexing scheme is as shown in Figure 4-1.

Table 7-3: 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: W/X <ul style="list-style-type: none"> • 0x 00 = Tracker Mode • 0x 01 = Beacon Mode | Tracker Mode 0x 00 | <i>tracker_beacon_mode: <value></i> <i>(unsigned/no unit)</i> |

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 §7.2.2.2.
- **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) is 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.

7.3.2 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 7-4. The default values of all other registers not listed in Table 7-4 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 7-4: 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 Sate | 0x 22 | 0x 00 3C | 0x 00 00 |
| Ticks per Geolocation Update in MOBILE Sate | 0x 23 | 0x 00 0A | 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 0-4 in Appendix 2.

8 Accelerometer Operation

The STORK is equipped with an accelerometer that can measure the direction and magnitude of acceleration on up to 3 individual axes: $\pm X$, $\pm Y$, and $\pm Z$.

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 and/or upon function button press.
- **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.

By default, orientation reporting is disabled, but motion detection alarms and accelerometer assist are enabled in tracker mode. 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.

8.1 General Sampling Behaviour

8.1.1 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: $\pm X$, $\pm Y$, and $\pm Z$.

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: 9.810 m/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 $\pm 2 g$, $\pm 4 g$, $\pm 8 g$, $\pm 16 g$ correspond to typical output precisions of 16 mg , 32 mg , 64 mg , 192 mg , respectively²³. If the physical acceleration magnitude is outside the current measurement range at the time of sampling, it will not be registered.

8.1.2 Configuration Settings

Table 8-5 shows the list of configuration registers which control general accelerometer behaviour. In this table, the bit indexing scheme is as shown in Figure 4-1. To access these registers, a command must be formatted and sent according to the details described in §4.3.2.

²³ The magnitudes are always reported by the sensor with $0.001 g = 1 \text{ mg}$ resolution, regardless of attainable precision given the current measurement range.

Table 8-1: 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 • Accelerometer on 0x 87 | <pre>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) }</pre> |
| 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 | <pre>accl_sensitivity: { sample_rate: <value>, (unsigned/Hz) measurement_range: <value> (unsigned/g) }</pre> |

8.1.2.1 Operational Configuration

The *Accelerometer Mode* register, 0x 40, controls 2 settings:

- *Accelerometer on/off*: setting bit 7 to 0 turns the accelerometer off, thereby disabling all accelerometer functions.
- *X/Y/Z Axis enable/disable*: individual axes can be enabled or disabled by setting the appropriate bits. When an axis is disabled, the value reported for that axis is always 0.

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 8-1.

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

8.1.2.2 Example DL Payloads

- Power on accelerometer and enable all axes:
 - DL payload: **0x C0 87**

- Register 0x 40 with bit 7 set to 1 = 0x C0
- Value bits 0, 1, 2, and 7 set to 1 = 0x 87

- 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

8.2 Orientation Detection

8.2.1 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*²⁴ 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.

8.2.2 UL Report Frame Formats

Accelerometer vector reports are sent on **LoRaWAN port 10** and have the frame format as shown in Figure 4-2. The specific details for the accelerometer vector report frame format are listed in Table 8-2. For the general description of sensor data report formats and behaviour, see §4.2.1.

Table 8-2: 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 | <ul style="list-style-type: none"> • [1 mg/LSb] (signed) • Bits 32-47: X-axis acceleration • Bits 16-31: Y-axis acceleration • Bits 0-15: Z-axis acceleration | <pre>acceleration_vector { xaxis: <value>, (signed/g) yaxis: <value>, (signed/g) zaxis: <value> (signed/g) }</pre> |

8.2.2.1 Example UL Payloads

- **0x 00 71 00 00 00 03 E8**
 - Channel ID = 0x 03, Type ID = 0x 72 → acceleration vector data report

²⁴ Acceleration magnitude is defined as $a = \|\vec{a}\| = \sqrt{x^2 + y^2 + z^2}$

- 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

8.2.3 Configuration Settings

Table 8-3 shows the list of configuration registers which affect accelerometer vector reporting behaviour. In addition to these registers, the configuration parameters listed in Table 8-1 also affect general accelerometer behaviour. In this table, the bit indexing scheme is as shown in Figure 4-1. To access these registers, a command must be formatted and sent according to the details described in §4.3.2.

Table 8-3: 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 <ul style="list-style-type: none"> • 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 | <i>seconds_per_core_tick:</i> <value> (unsigned/s) |
| 0x 24 | Ticks per Accelerometer | 2 B | Access R/W <ul style="list-style-type: none"> • Ticks between accelerometer vector reports • Acceptable values: 0, 1, 2, ..., 65535 • 0: disables periodic accelerometer vector reports | Periodic reporting disabled 0x 00 00 | <i>ticks_per_accelerometer:</i> <value> (unsigned/no unit) |

8.2.3.1 Periodic Reporting Configuration

The accelerometer vector reporting period can be configured using registers 0x 20 and 0x 24 according to the equation described in §5.2.2. That is:

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

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

8.2.3.2 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

8.3 Motion Detection Alarms

8.3.1 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***.

Motion Detected:

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 8-1.

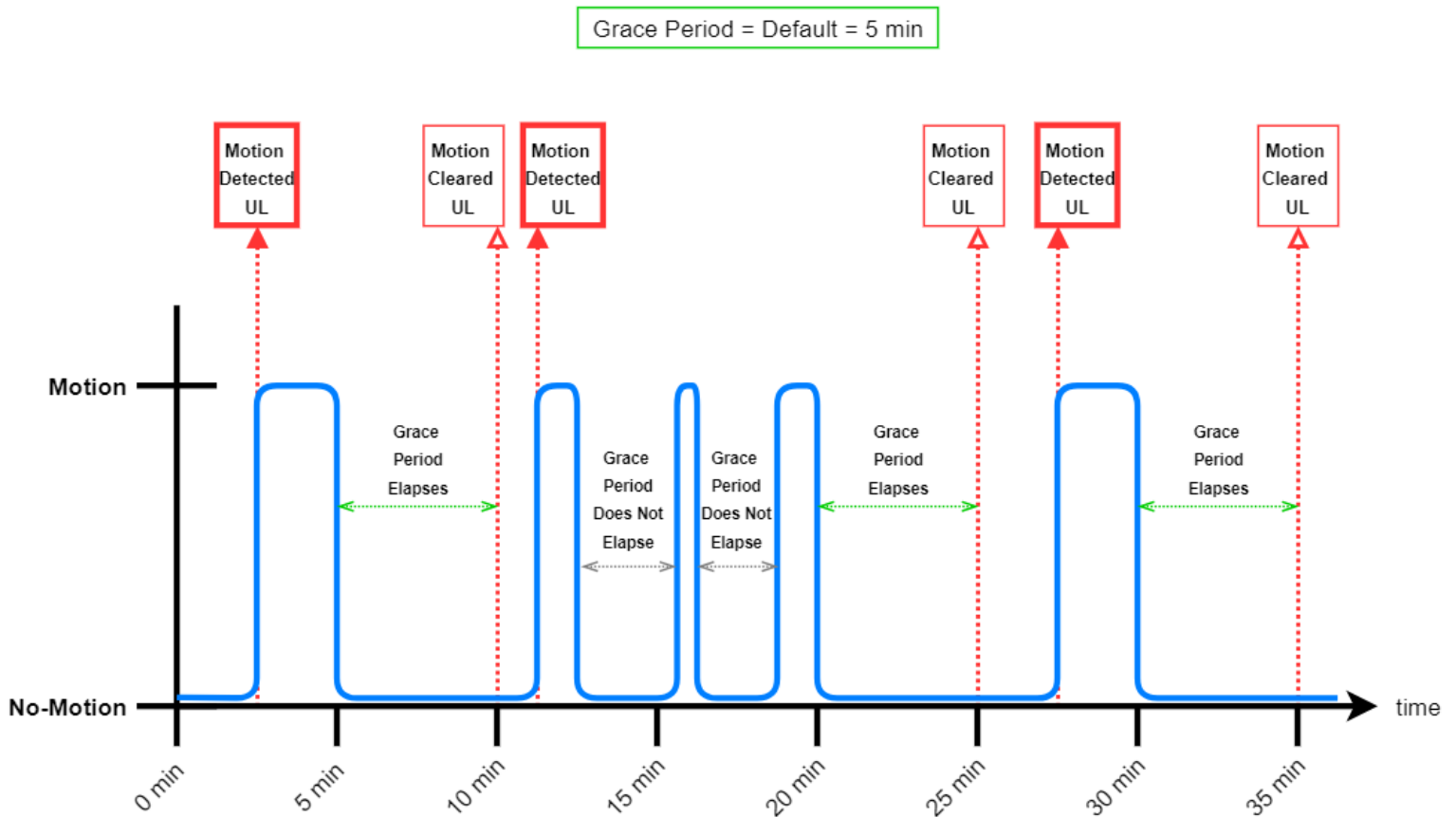


Figure 8-1: Example Sequence of Accelerometer Events and UL Reports

8.3.2 UL Report Frame Formats

Accelerometer alarm reports are sent on **LoRaWAN port 10** and have the frame format as shown in Figure 4-2. The specific details for the alarm report frame format are listed in Table 8-4. For the general description of sensor data report formats and behaviour, see §4.2.1.

Table 8-4: 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 | <ul style="list-style-type: none"> 0x 00 = Alarm inactive (motion no longer detected) 0x FF = Alarm active (motion detected) | <i>acceleration_alarm (unsigned/no unit)</i> |

8.3.2.1 Example UL Payloads

- **0x 00 00 FF**
 - 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

8.3.3 Configuration Settings

Table 8-5 shows the list of configuration registers which affect accelerometer alarm reporting behaviour. In addition to these registers, the configuration parameters listed in Table 8-1 also affect general accelerometer behaviour. In these tables the bit indexing scheme is as shown in Figure 4-1. To access these registers, a command must be formatted and sent according to the details described in §4.3.2.

Table 8-5: 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 <ul style="list-style-type: none"> • Number of above-threshold acceleration samples before an acceleration trigger is registered • Acceptable values: <ul style="list-style-type: none"> ≥ 1 • 0: <ul style="list-style-type: none"> Invalid and ignored | 1 trigger 0x 00 01 | <i>accl_trigger_threshold_count:</i> <i><value></i> <i>(unsigned/no unit)</i> |
| 0x 43 | Acceleration Trigger Threshold Period | 2 B | Access: R/W <ul style="list-style-type: none"> • Period over which acceleration samples are counted for trigger detection [1s/LSb] • Acceptable values: <ul style="list-style-type: none"> ≥ 5 • 0-4: <ul style="list-style-type: none"> Invalid and ignored | 10 seconds 0x 00 0A | <i>accl_trigger_threshold_period:</i> <i><value></i> <i>(unsigned/s)</i> |
| 0x 44 | Acceleration Trigger Threshold | 2 B | Access: R/W <ul style="list-style-type: none"> • Acceleration magnitude threshold for acceleration trigger [1 mg/LSb] | 2 g 0x 07 D0 | <i>accl_trigger_threshold: <value></i> <i>(unsigned/mg)</i> |

| Address | Value | Size | Description and Options | Default Value | JSON Variable (Type/Unit) |
|---------|---------------------------------|------|---|--|---|
| 0x 45 | Acceleration Event Grace Period | 2 B | Access: R/W <ul style="list-style-type: none"> Time to pass after the last accelerometer trigger before the event is cleared [1s/LSb] Acceptable values: <ul style="list-style-type: none"> ≥ 15 0-14: Invalid and ignored | 5 min 0x 01 2C | <i>accl_event_grace_period:</i> <value> (unsigned/s) |
| 0x 46 | Acceleration Event Value to Tx | 1 B | Access: R/W <ul style="list-style-type: none"> Bit 0: 0/1 = Acceleration alarm UL report disabled/enabled Bit 1: 0/1 = Accelerometer Assist for geolocation disabled/enabled Bits 2-7: Ignored | <ul style="list-style-type: none"> Acceleration alarm report UL enabled Accelerometer Assist enabled 0x 03 | <pre>accl_tx: { accl_alarms: <value>, (unsigned/no unit) accl_assist: <value>, (unsigned/no unit) }</pre> |

8.3.3.1 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 §8.4 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.

8.3.3.2 Example DL Payloads

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

8.4 Accelerometer Assist for Geolocation

8.4.1 Operational Description

In addition to motion detection alarm reporting as described in §8.3, *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 §6.1.3.1). 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 asset tracking, Accelerometer Assisted geolocation scans help to get location updates at appropriate rates: faster when the asset is moving and slower when still. Accelerometer Assist also helps to update the location at 2 critical times; when assets 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 §8.3.1 for details on how these are registered.

Accelerometer Assist is enabled by default in tracker mode and permanently disabled in beacon mode.

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

8.4.2 Configuration Settings

Table 8-6 shows the list of configuration registers which affect Accelerometer Assist behaviour. In addition to these registers, the configuration parameters listed in Table 8-1 also affect general accelerometer behaviour. In these tables the bit indexing scheme is as shown in Figure 4-1. To

access these registers, a command must be formatted and sent according to the details described in §4.3.2.

Table 8-6: 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 <ul style="list-style-type: none"> • Number of above-threshold acceleration samples before an acceleration trigger is registered • Acceptable values: ≥ 1 • 0: Invalid and ignored | 1 trigger 0x 00 01 | <i>accl_trigger_threshold_count:</i> <value> (unsigned/no unit) |
| 0x 43 | Acceleration Trigger Threshold Period | 2 B | Access: R/W <ul style="list-style-type: none"> • 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 | <i>accl_trigger_threshold_period:</i> <value> (unsigned/s) |
| 0x 44 | Acceleration Trigger Threshold | 2 B | Access: R/W <ul style="list-style-type: none"> • Acceleration magnitude threshold for acceleration trigger [1 mg/LSb] | 2 g 0x 07 D0 | <i>accl_trigger_threshold:</i> <value> (unsigned/mg) |
| 0x 45 | Acceleration Event Grace Period | 2 B | Access: R/W <ul style="list-style-type: none"> • 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 | <i>accl_event_grace_period:</i> <value> (unsigned/s) |
| 0x 46 | Acceleration Event Value to Tx | 1 B | Access: R/W <ul style="list-style-type: none"> • Bit 0: 0/1 = Acceleration alarm UL report disabled/enabled • Bit 1: 0/1 = Accelerometer Assist for geolocation disabled/enabled • Bits 2-7: RFU | <ul style="list-style-type: none"> • Acceleration alarm report UL enabled • Accelerometer Assist enabled 0x 03 | <i>accl_tx:</i> { <i>accl_alarms:</i> <value>, (unsigned/no unit) <i>accl_assist_ble:</i> <value>, (unsigned/no unit) } |

8.4.2.1 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 §8.3 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.

8.4.2.2 Example DL Payloads

- Change threshold value to 800 mg:
 - DL payload: 0x **C4 03 20**
 - Register 0x 44 with bit 7 set to 1 = 0x C4
 - 800 mg = 0x 03 20

- Read *Acceleration Event Value to Tx*:
 - DL payload: **0x 46**
 - Register 0x 46 with bit 7 set to 0 = 0x 46

9 Ambient Environment Sensing

The STORK is equipped with an onboard transducer that functions as both a thermometer and hygrometer. The vents in the enclosure (shown in Figure 3-1) allow the ambient air to flow through the sensor so that the *temperature* [°C] and *relative humidity (RH)* [%] data can be reported in a LoRaWAN UL.

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

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

9.1 Temperature and RH Reporting

9.1.1 Operational Description

The STORK samples the temperature and humidity readings during the background of normal operation. It can be configured to periodically report the temperature in [°C] and RH in [%] in a LoRaWAN UL. Sampling cannot be disabled, but reporting can be disabled.

By default, both temperature and RH are reported every hour.

NOTE: During ambient temperature or RH changes, it may take some time for the sensor to report the new ambient 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.

9.1.2 UL Report Frame Formats

Ambient environment data reports are sent on **LoRaWAN port 10** and have the frame format as shown in Figure 4-2. The specific details for the frame formats are listed in Table 9-1. For the general description of sensor data report formats and behaviour, see §4.2.1.

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) |
|---------------------------|------------|---------|------|-------------|-------------------------|--|
| Ambient Temperature | 0x 03 | 0x 67 | 2 B | Temperature | • [0.1°C/LSb] (signed) | <i>temperature: <value></i> <i>(signed/°C)</i> |
| Ambient Relative Humidity | 0x 04 | 0x 68 | 2 B | Humidity | • [0.5%/LSb] (unsigned) | <i>relative_humidity: <value></i> <i>(unsigned/%)</i> |

9.1.2.1 Example UL Payloads

- **0x 03 67 00 96**
 - Channel ID = 0x 03, Type ID = 0x 67 → ambient temperature data report
 - 0x 00 96 = 150 × 0.1°C = 15°C
- **0x 04 68 54**
 - Channel ID = 0x 04, Type ID = 0x 68 → ambient RH data report
 - 0x 54 = 84 × 0.5% = 42%

9.1.3 Configuration Settings

Table 9-2 shows the list of configuration registers which control periodic ambient environment data reporting behaviour. In this table, the bit indexing scheme is as shown in Figure 4-1. To

access these registers, a command must be formatted and sent according to the details described in §4.3.2.

Table 9-2: Ambient Environment 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 <ul style="list-style-type: none"> • 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 | <i>seconds_per_core_tick:</i> <value> (unsigned/s) |
| 0x 25 | Ticks per Temperature | 2 B | Access R/W <ul style="list-style-type: none"> • Ticks between ambient temperature reports • Acceptable values: 0, 1, 2, ..., 65535 • 0 disables periodic temperature reports | 60 ticks = 1 hr period 0x 00 3C | <i>ticks_per_ambient_temp:</i> <value> (unsigned/no unit) |
| 0x 26 | Ticks per Relative Humidity | 2 B | Access R/W <ul style="list-style-type: none"> • Ticks between ambient RH reports • Acceptable values: 0, 1, 2, ..., 65535 • 0 disables periodic RH reports | 60 ticks = 1 hr period 0x 00 3C | <i>ticks_per_ambient_rh:</i> <value> (unsigned/no unit) |

9.1.3.1 Periodic Reporting Configuration

The ambient temperature and RH reporting periods can be configured using registers 0x 20, 0x 25, and 0x 26 according to the equation described in §5.2.2. That is:

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

$$\text{Relative Humidity Reporting Period} = \text{Seconds per Core Tick} \times \text{Ticks per Relative}$$

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

9.1.3.2 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 25 with bit 7 set to 1 = 0x A5

- Report every 48 ticks = 0x 00 30
- Disable RH reporting:
 - DL payload: **0x A6 00 00**
 - Register 0x 26 with bit 7 set to 1 = 0x A6
 - Disable periodic reporting = 0x 00 00

9.2 Threshold-Based Reporting

9.2.1 Operational Description

In addition to periodic ambient environment data reporting, the STORK supports sending additional data reports based on crossing configurable thresholds. Both temperature and RH thresholds can be set.

When an environmental temperature threshold is enabled, the sensor reports the environment 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 environment data is equal to the *low threshold* or *high threshold*, the sensor is considered to have left the threshold window.

When the environment data is inside the threshold window, the STORK is in the *idle* sampling state. When outside, the STORK is in the *active* sampling state. This is illustrated using the default configurations in Figure 9-1.

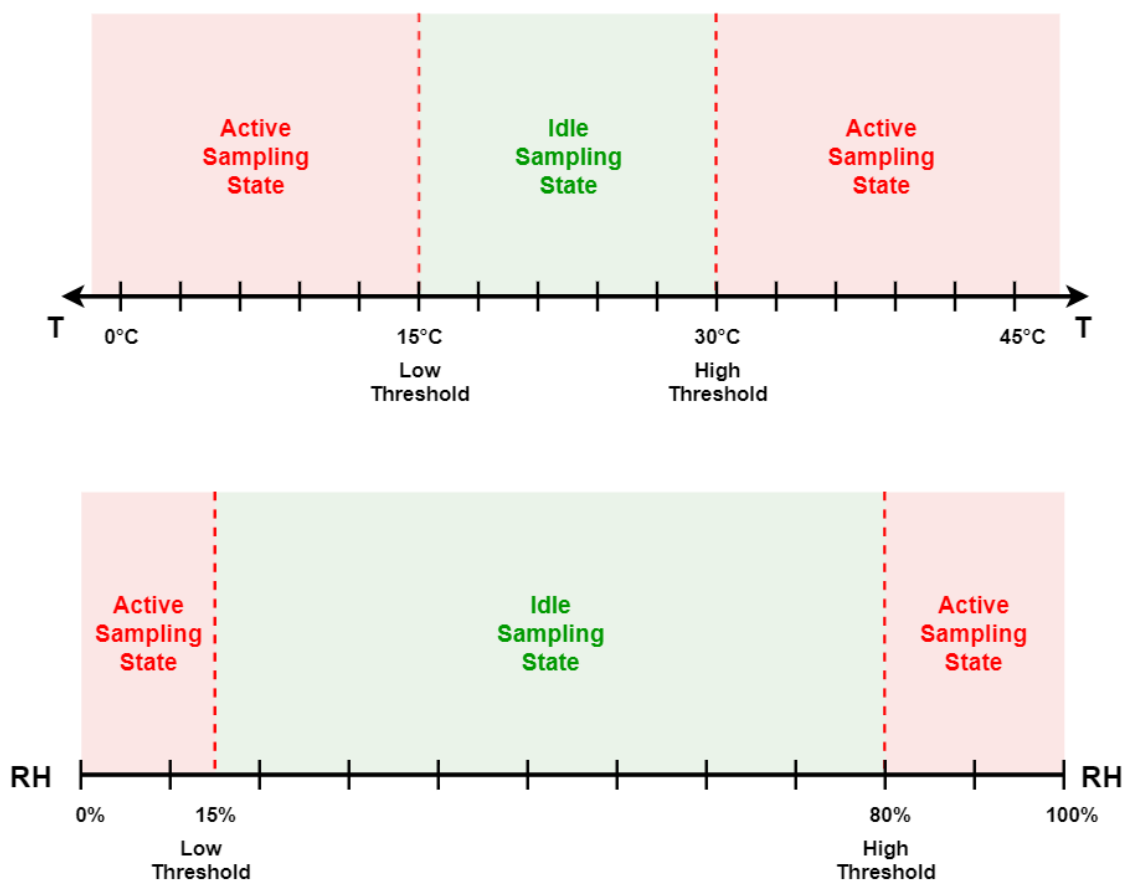


Figure 9-1: Default Ambient Temperature and RH Threshold Windows

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

By default, threshold-based reporting is disabled.

Threshold-based reporting is compatible with periodic reporting of the ambient environment data; both can be disabled and enabled independently²⁵.

9.2.2 UL Report Frame Formats

The UL report frame formats for threshold-based reports are identical to those for periodic reports, See §9.1.2.

9.2.3 Configuration Settings

Table 9-3 shows the list of configuration registers which affect accelerometer vector reporting behaviour. In addition to these registers, the configuration parameters listed in Table 8-1 also affect general accelerometer behaviour. In this table, the bit indexing scheme is as shown in Figure 4-1. To access these registers, a command must be formatted and sent according to the details described in §4.3.2.

Table 9-3: Ambient Environment Data Threshold Configuration Registers

| Address | Name | Size | Description and Options | Default Value | JSON Variable (Type/Unit) |
|---------|---|------|---|-----------------------------------|---|
| 0x 39 | Temperature/ RH Sample Period: Idle | 4 B | Access: R/W <ul style="list-style-type: none"> • Sample period of ambient temperature/RH 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 | <i>temp_rh_sample_period_idle: <value></i> <i>(unsigned/sec)</i> |
| 0x 3A | Temperature/ RH Sample Period: Active | 4 B | Access: R/W <ul style="list-style-type: none"> • Sample period of ambient temperature/RH 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 | <i>temp_rh_sample_period_active: <value></i> <i>(unsigned/sec)</i> |

²⁵ See §9.1 for details about periodic MCU temperature reporting configuration.

| Address | Name | Size | Description and Options | Default Value | JSON Variable (Type/Unit) |
|---------|---------------------------------|------|---|--|---|
| 0x 3B | Low/High Temperature Thresholds | 2 B | Access: R/W <ul style="list-style-type: none"> Bits 8-15: High ambient temperature threshold (signed) [1°C/LSb] Bits 0-7: Low ambient temperature threshold (signed) [1°C/LSb] High threshold \leq Low threshold: Invalid and ignored | <ul style="list-style-type: none"> High threshold = 30°C Low threshold = 15°C <p>0x 1E 0F</p> | <i>temp_threshold_high: <value></i> <i>(signed/°C)</i> <i>temp_threshold_low: <value></i> <i>(signed/°C)</i> |
| 0x 3C | Temperature Thresholds Enabled | 1 B | Access: R/W <ul style="list-style-type: none"> Bit 0: 0/1: Ambient temperature thresholds disabled/enabled Bits 1-7: RFU | Disabled <p>0x 00</p> | <i>temp_thresholds_enabled: <value></i> <i>(string/no unit)</i> |
| 0x 3D | Low/High RH Thresholds | 2 B | Access: R/W <ul style="list-style-type: none"> Bits 8-15: High ambient RH threshold (signed) [0.5%/LSb] Bits 0-7: Low ambient RH threshold (signed) [0.5%/LSb] High threshold \leq Low threshold: Invalid and ignored | <ul style="list-style-type: none"> High threshold = 80% Low threshold = 15% <p>0x 50 0F</p> | <i>rh_threshold_high: <value></i> <i>(unsigned/%)</i> <i>rh_threshold_low: <value></i> <i>(unsigned/%)</i> |
| 0x 3E | RH Thresholds Enabled | 1 B | Access: R/W <ul style="list-style-type: none"> Bit 0: 0/1: Ambient RH thresholds disabled/enabled Bits 1-7: RFU | Disabled <p>0x 00</p> | <i>rh_thresholds_enabled: <value></i> <i>(string/no unit)</i> |

9.2.3.1 Operational Configuration

The thresholds enabled registers 0x 3C and 0x 3E enable and disable the ambient temperature and RH 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 ambient temperature thresholds are defined by register 0x 3B with a 1°C precision. The ambient RH thresholds are defined by register 0x 3D with a 0.5% precision. The high threshold must be greater than the low threshold in both cases.

9.2.3.2 Example DL Payloads

- Enable temperature threshold-based reporting with a window between -10°C and 35°C:
 - DL payload: **0x BB 23 F6 BC 01**
 - Register 0x 3B with bit 7 set to 1 = 0x 3B
 - High MCU temperature threshold = 35°C = 0x 23
 - Low MCU temperature threshold = -10°C = 0x F6

- Register 0x 3C with bit 7 set to 1 = 0x BC
- Thresholds enabled = 0x 01

- Read current sample periods:
 - DL payload: **0x 39 3A**
 - Registers 0x 39 and 0x 3A with bits 7 set to 0 = 0x 39 3A

Appendix 1 – List of UL Frame Formats

LoRaWAN Port 10 and 16 UL Frame Formats

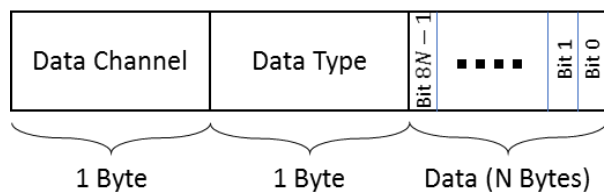


Figure 0-1: The UL Frame Format for a Sensor Data or GNSS Diagnostics Report

Table 0-1: 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) |
|----------------------------|------------|---------|------|---------------|--|--|
| Remaining Battery Capacity | 0x 00 | 0x D3 | 1 B | Percentage | <ul style="list-style-type: none"> 1% / LSB (unsigned) | <i>rem_batt_capacity: <value> (unsigned/%)</i> |
| Remaining Battery Lifetime | 0x 00 | 0x BD | 2 B | Days | <ul style="list-style-type: none"> 1 day / LSB (unsigned) | <i>rem_batt_days: <value> (unsigned/days)</i> |
| Geolocation Cycle Failed | 0x 00 | 0x 95 | 1 B | Bitmap Input | <ul style="list-style-type: none"> Bits 0-1: GNSS Scan <ul style="list-style-type: none"> 00: Scan failed 11: Scan successful or scan not done Bit 2: Wi-Fi scan <ul style="list-style-type: none"> 0: Scan failed 1: Scan successful or scan not done Bit 3: BLE scan <ul style="list-style-type: none"> 0: Scan failed 1: Scan successful or scan not done Bit 4: LoRaWAN duty cycle <ul style="list-style-type: none"> 0: GNSS and/or Wi-Fi scan results dropped due to duty cycle restrictions 1: No duty cycle restriction impacts Bits 5-7: all 0 (RFU) | <i>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) }</i> |
| Acceleration Alarm Status | 0x 00 | 0x 00 | 1 B | Digital Input | <ul style="list-style-type: none"> 0x 00 = Alarm inactive (motion no longer detected) 0x FF = Alarm active (motion detected) | <i>acceleration_alarm (unsigned/no unit)</i> |
| Acceleration Vector | 0x 00 | 0x 71 | 6 B | Acceleration | <ul style="list-style-type: none"> [1 mg/LSb] (signed) Bits 32-47: X-axis acceleration Bits 16-31: Y-axis acceleration Bits 0-15: Z-axis acceleration | <i>acceleration_vector { xaxis: <value>, (signed/g) yaxis: <value>, (signed/g) zaxis: <value> (signed/g) }</i> |
| Ambient Temperature | 0x 03 | 0x 67 | 2 B | Temperature | <ul style="list-style-type: none"> [0.1°C/LSb] (signed) | <i>temperature: <value> (signed/°C)</i> |
| Ambient Relative Humidity | 0x 04 | 0x 68 | 2 B | Humidity | <ul style="list-style-type: none"> [0.5%/LSb] (unsigned) | <i>relative_humidity: <value> (unsigned/%)</i> |

Table 0-2: Complete List of LoRaWAN Port 16 GNSS Diagnostics Frame Formats

| Information Type | Channel ID | Type ID | Size | Data Type | Data Format | JSON Variable (Type/Unit) |
|-----------------------------------|------------|---------|------|-----------|---|---|
| Number of Visible Satellites | 0x 0D | 0x 3C | 1 B | Integer | <ul style="list-style-type: none"> Bits 7-0: Number of satellites detected (unsigned) | <i>num_satellites: <value> (unsigned/no unit)</i> |
| Average Satellite SNR | 0x 0D | 0x 64 | 2 B | Generic | <ul style="list-style-type: none"> Bits 15-0: Average SNR of all satellites [0.1 dB/LSb] (signed) 0x 00 00 = No satellites visible for calculating average | <i>avg_satellite_snr: <value> (signed/dB)</i> |
| Minimum and Maximum Satellite SNR | 0x 0D | 0x 63 | 4 B | Generic | <ul style="list-style-type: none"> Bits 15-0: Minimum SNR of all satellites [0.1 dB/LSb] (signed) Bits 31-16: Maximum SNR of all satellites [0.1 dB/LSb] (signed) 0x 00 00 00 00 = No satellites visible for calculating average | <i>min_max_satellite_snr: { min: <value>, (signed/dB) maxi: <value>, (signed/dB) ble: <value>, (unsigned/no unit) }</i> |

LoRaWAN Port 25 UL Frame Formats

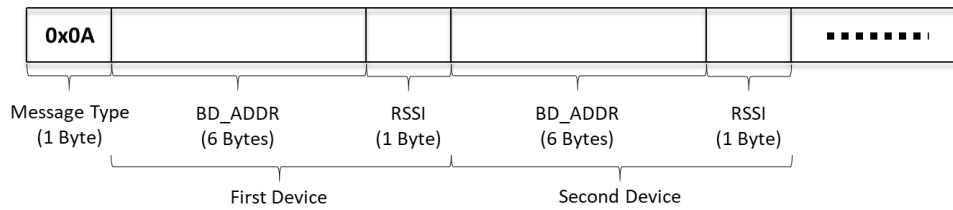
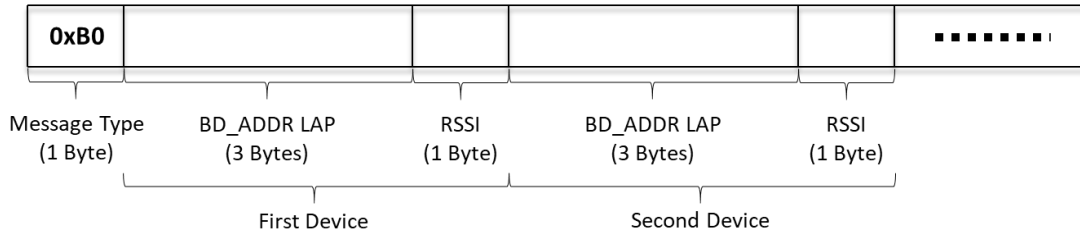
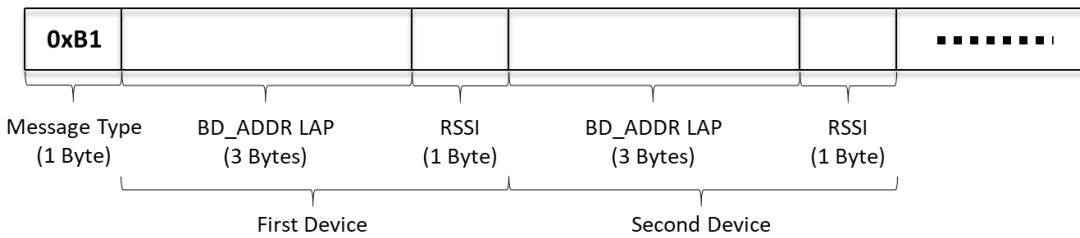


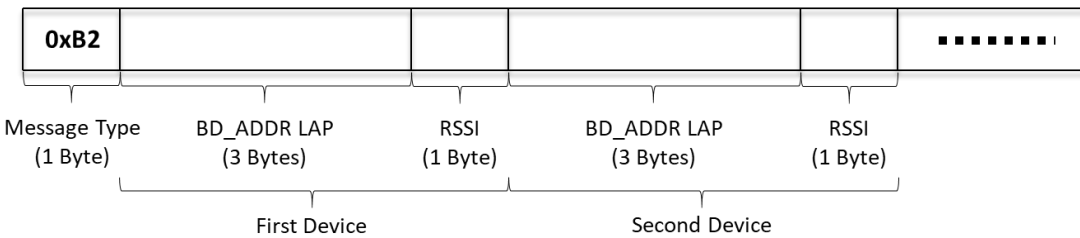
Figure 0-2: The BLE Report UL Payload Format for Basic Reporting



(a) Filter Range 0



(b) Filter Range 1



(c) Filter Range 2



(d) Filter Range 3

Figure 0-3: BLE Report UL Payload Formats for Filtered Reporting

LoRaWAN Port 100 and 101 UL Frame Formats

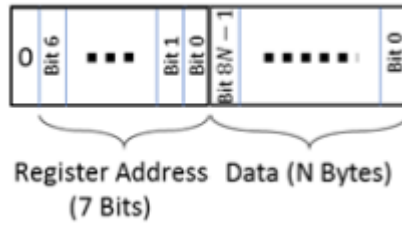


Figure 0-4: The LoRaWAN Port 100 Read Response Format

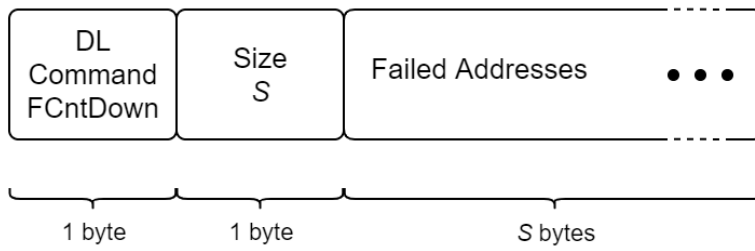


Figure 0-5: The LoRaWAN port 101 Write Response Format

LoRaWAN Port 192 and 197 UL Frame Formats

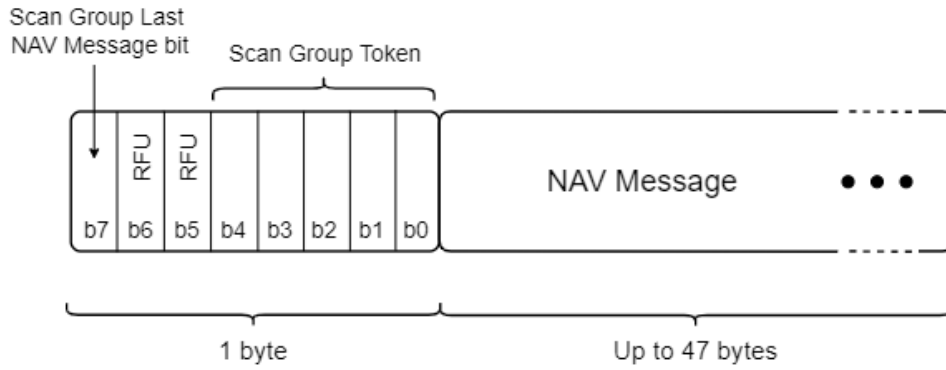


Figure 0-6: The LoRaWAN Port 192 GNSS Scan Results UL Frame Format

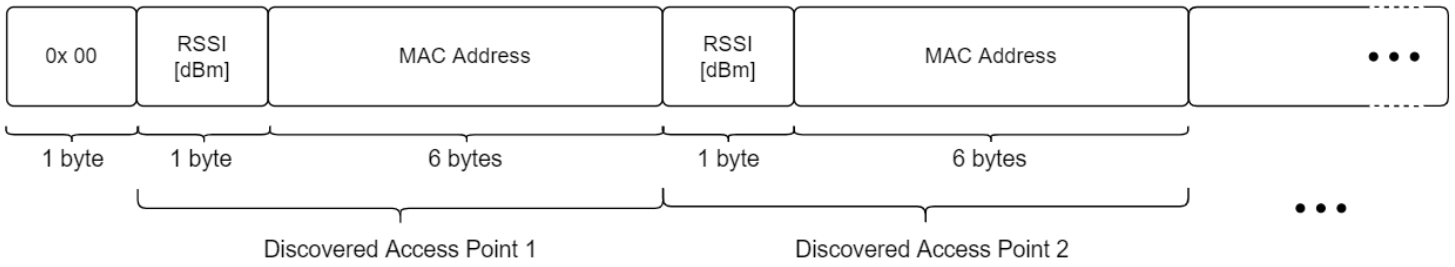
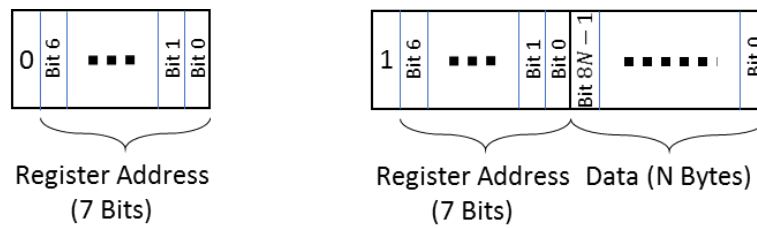


Figure 0-7: The LoRaWAN Port 197 Wi-Fi Scan Results UL Frame Format

Appendix 2 – Lists of Configuration Registers and DL Payload Formats



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

Figure 0-8: The LoRaWAN Port 100 DL Formats for Configuration and Control Message Blocks

Table 0-3: Complete List of Configuration Registers

| Address | Name | Size | Description and Options | Default Value | JSON Variable (Type/Unit) |
|---------|-------------------------------|------|--|---|---|
| 0x 0A | Tracker / Beacon Mode | 1 B | Access: W/X <ul style="list-style-type: none"> 0x 00 = Tracker Mode 0x 01 = Beacon Mode | Tracker Mode 0x 00 | <i>tracker_beacon_mode</i> : <value> (unsigned/no unit) |
| 0x 11 | Options | 2 B | Access: R/W (bits 1 and 2 are RO) <ul style="list-style-type: none"> 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 | <ul style="list-style-type: none"> Unconfirmed UL Public Sync Word Duty cycle enabled ADR disabled 0x 00 06 | <i>loramac_opts</i> : { <i>confirm_mode</i> : <value>, (unsigned/no unit) <i>sync_word</i> : <value>, (unsigned/no unit) <i>duty_cycle</i> : <value>, (unsigned/no unit) <i>adr</i> : <value> (unsigned/no unit) } |
| 0x 12 | DR and Tx Power ²⁶ | 2 B | Access: R/W <ul style="list-style-type: none"> Bits 8-11: Default DR number Bits 0-3: Default Tx power number Bits 4-7, 12-15: Ignored | <ul style="list-style-type: none"> DR3 Tx Power 0 (max power; see Table 5-2) 0x 03 00 | <i>loramac_dr_tx</i> : { <i>dr_number</i> : <value>, (unsigned/no unit) <i>tx_power_number</i> : <value> (unsigned/no unit) } |
| 0x 20 | Seconds per Core Tick | 4 B | Access R/W <ul style="list-style-type: none"> 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 | <i>seconds_per_core_tick</i> : <value> (unsigned/s) |

²⁶ Tx power number m translates to the maximum Tx power, which is a function of the LoRaWAN RF region, minus $2 \times m$ dB [2].

| Address | Name | Size | Description and Options | Default Value | JSON Variable (Type/Unit) |
|---------|--|------|---|--|---|
| 0x 21 | Ticks per Battery | 2 B | Access R/W <ul style="list-style-type: none"> • Ticks between battery reports • Acceptable values: 1, 2, 3, ..., 65535 • 0: Invalid and ignored | 1440 ticks = 1 day period 0x 05 A0 | <i>ticks_per_battery: <value></i> <i>(unsigned/no unit)</i> |
| 0x 22 | Ticks per Geolocation Update in STILL State | 2 B | Access R/W <ul style="list-style-type: none"> • 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 | <i>ticks_per_geolocation_update_stillness: <value></i> <i>(unsigned/no unit)</i> |
| 0x 23 | Ticks per Geolocation Update in MOBILE State | 2 B | Access R/W <ul style="list-style-type: none"> • 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 | <i>ticks_per_geolocation_update_mobility: <value></i> <i>(unsigned/no unit)</i> |
| 0x 24 | Ticks per Accelerometer | 2 B | Access R/W <ul style="list-style-type: none"> • Ticks between accelerometer vector reports • Acceptable values: 0, 1, 2, ..., 65535 • 0 disables periodic accelerometer vector reports | Periodic reporting disabled 0x 00 00 | <i>ticks_per_accelerometer: <value></i> <i>(unsigned/no unit)</i> |
| 0x 25 | Ticks per Temperature | 2 B | Access R/W <ul style="list-style-type: none"> • Ticks between ambient temperature reports • Acceptable values: 0, 1, 2, ..., 65535 • 0 disables periodic temperature reports | 60 ticks = 1 hr period 0x 00 3C | <i>ticks_per_ambient_temp: <value></i> <i>(unsigned/no unit)</i> |
| 0x 26 | Ticks per Relative Humidity | 2 B | Access R/W <ul style="list-style-type: none"> • Ticks between ambient RH reports • Acceptable values: 0, 1, 2, ..., 65535 • 0 disables periodic RH reports | 60 ticks = 1 hr period 0x 00 3C | <i>ticks_per_ambient_rh: <value></i> <i>(unsigned/no unit)</i> |

| Address | Name | Size | Description and Options | Default Value | JSON Variable (Type/Unit) |
|---------|------------------------------|------|--|--|--|
| 0x 30 | Geolocation Strategy | 1 B | <p>Access: R/W</p> <ul style="list-style-type: none"> • Bits 0-1: 1st priority scan <ul style="list-style-type: none"> ○ 01: BLE ○ 10: WIFI ○ 11: GNSS ○ 00: Invalid and ignored • Bits 2-3: 2nd priority scan <ul style="list-style-type: none"> ○ 00: Not defined ○ 01: BLE ○ 10: WIFI ○ 11: GNSS • Bits 4-5: 3rd priority scan <ul style="list-style-type: none"> ○ 00: Not defined ○ 01: BLE ○ 10: WIFI ○ 11: GNSS • Bits 6-7: Scan order logic option (see Table 6-2) <ul style="list-style-type: none"> ○ 00: A ○ 01: B ○ 10: C ○ 11: D • Restrictions: <ul style="list-style-type: none"> ○ 2nd scan must be defined to set 3rd scan <p>Scan types can only be defined once</p> | <ul style="list-style-type: none"> • 1st priority scan: GNSS • 2nd priority scan: Wi-Fi • 3rd priority scan: BLE • Scan order logic option A <p>0b 00 01 10 11 or 0x 1B</p> | <pre>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) }</pre> |
| 0x 32 | GNSS Diagnostics Value to Tx | 1 B | <p>Access: R/W</p> <ul style="list-style-type: none"> • Bit 0: <ul style="list-style-type: none"> ○ 0/1 = Number of Visible Satellites report disabled/enabled • Bit 1: <ul style="list-style-type: none"> ○ 0/1 = Average Satellite SNR report disabled/enabled • Bit 6: <ul style="list-style-type: none"> ○ 0/1 = Max and min satellite SNR report disabled/enabled • Bits 2-5, 7: <ul style="list-style-type: none"> ○ RFU | <p>No diagnostics reported</p> <p>0x 00</p> | <pre>gnss_diagnostics_tx { num_satellites: <value>, (unsigned/no unit) avg_satellite_snr: <value>, (unsigned/no unit) min_max_satellite_snr: <value>, (unsigned/no unit) }</pre> |
| 0x 33 | Clock Sync Configuration | 1 B | <p>Access: R/W</p> <ul style="list-style-type: none"> • Bits 0-3: clock sync interval m, [1 day/LSb] <ul style="list-style-type: none"> ○ Acceptable values: $0 \leq m \leq 15$ ○ 0: Disables clock sync • Bits 4-6: Invalid clock delay multiplier, n <ul style="list-style-type: none"> ○ Acceptable values: $1 \leq n \leq 7$ ○ 0: Invalid and ignored • Bit 7: Clock sync service <ul style="list-style-type: none"> ○ 0: LoRaMAC clock sync ○ 1: LoRa Cloud clock sync | <ul style="list-style-type: none"> • $m = 7$ days = 1 week • $n = 4 \rightarrow 4$ weeks • LoRa Cloud clock sync service <p>0x C7</p> | <pre>clock_sync: { interval: <value>, (unsigned/days) invalid_delay_multiplier: <value>, (unsigned/no unit) service: <value>, (unsigned/no unit) }</pre> |

| Address | Name | Size | Description and Options | Default Value | JSON Variable (Type/Unit) |
|---------|--------------------------------------|------|---|--|--|
| 0x 34 | Almanac Update Request Period | 2 B | <p>Access: R/W</p> <ul style="list-style-type: none"> Interval between sending almanac update requests ULs [1 s/LSb] Acceptable values: 10, 11, 12, ..., 65535 Other values: Invalid and ignored | <p>30 seconds</p> <p>0x 00 1E</p> | <p><i>almanac_update_request_period</i>: <value>, (unsigned/s)</p> |
| 0x 35 | Almanac Update Check Period | 1 B | <p>Access: R/W</p> <ul style="list-style-type: none"> Interval between sending almanac update check ULs [1 day/LSb] Acceptable values: 0, 1, 2, ..., 90 Other values: invalid and ignored 0: Disables almanac update checking | <p>1 day</p> <p>0x 01</p> | <p><i>almanac_update_check_period</i>: <value>, (unsigned/s)</p> |
| 0x 36 | Assist Coordinates | 8 B | <p>Access: R/W</p> <ul style="list-style-type: none"> Bit 0: <ul style="list-style-type: none"> 0/1: disable/enable assist coordinates Bits 1-15: RFU Bits 16-39: Longitude y [(180°/2²³)/LSb ≈ 0.000002°/LSb] <ul style="list-style-type: none"> Acceptable values: -180 ≤ y ≤ 180 Bits 40-63: Latitude x [(90°/2²³)/LSb ≈ 0.000001°/LSb] <ul style="list-style-type: none"> Acceptable values: -90 ≤ x ≤ 90 | <ul style="list-style-type: none"> Assist coordinates disabled $x = 0^\circ$ $y = 0^\circ$ <p>0x 00 00 00 00 00 00 00 00</p> | <p><i>assist_coordinates</i>: {</p> <p><i>latitude</i>: <value>, (signed/°)</p> <p><i>longitude</i>: <value>, (signed/°)</p> <p><i>enabled</i>: <value>, (unsigned/no unit)</p> <p>}</p> |
| 0x 37 | GNSS Satellite Constellation Option | 1 B | <p>Access: R/W</p> <ul style="list-style-type: none"> 0x 00: GPS 0x 01: BeiDou 0x 02: GPS and BeiDou Other values: invalid and ignored | <p>GPS and BeiDou</p> <p>0x 02</p> | <p><i>gnss_constellation_option</i>: <value> (unsigned, no unit)</p> |
| 0x 38 | Default GNSS Scan Mode | 1 B | <p>Access: R/W</p> <ul style="list-style-type: none"> Default GNSS scan mode when the accelerometer is not enabled 0x 00: Static scanning mode 0x 01: Mobile scanning mode Other values: invalid and ignored | <p>Mobile scanning mode</p> <p>0x 01</p> | <p><i>default_gnss_scan_mode</i>: <value> (unsigned, no unit)</p> |
| 0x 39 | Temperature/RH Sample Period: Idle | 4 B | <p>Access: R/W</p> <ul style="list-style-type: none"> Sample period of ambient temperature/RH data when in idle state [1 s/LSB] Acceptable values: 10, 11, ..., 86400 Other values: Invalid and ignored | <p>60 s</p> <ul style="list-style-type: none"> 0x 00 00 00 3C | <p><i>temp_rh_sample_period_idle</i>: <value> (unsigned/sec)</p> |
| 0x 3A | Temperature/RH Sample Period: Active | 4 B | <p>Access: R/W</p> <ul style="list-style-type: none"> Sample period of ambient temperature/RH data when in active state [1 s/LSB] Acceptable values: 10, 11, ..., 86400 Other values: Invalid and ignored | <p>30 s</p> <ul style="list-style-type: none"> 0x 00 00 00 1E | <p><i>temp_rh_sample_period_active</i>: <value> (unsigned/sec)</p> |

| Address | Name | Size | Description and Options | Default Value | JSON Variable (Type/Unit) |
|---------|---------------------------------|------|--|--|---|
| 0x 3B | Low/High Temperature Thresholds | 2 B | Access: R/W <ul style="list-style-type: none"> • Bits 8-15: High ambient temperature threshold (signed) [1°C/LSb] • Bits 0-7: Low ambient temperature threshold (signed) [1°C/LSb] • High threshold ≤ Low threshold: Invalid and ignored | <ul style="list-style-type: none"> • High threshold = 30°C • Low threshold = 15°C <p>0x 1E 0F</p> | <i>temp_threshold_high</i> : <value> (signed/°C) <i>temp_threshold_low</i> : <value> (signed/°C) |
| 0x 3C | Temperature Thresholds Enabled | 1 B | Access: R/W <ul style="list-style-type: none"> • Bit 0: 0/1: Ambient temperature thresholds disabled/enabled • Bits 1-7: RFU | Disabled <p>0x 00</p> | <i>temp_thresholds_enabled</i> : <value> (string/no unit) |
| 0x 3D | Low/High RH Thresholds | 2 B | Access: R/W <ul style="list-style-type: none"> • Bits 8-15: High ambient RH threshold (signed) [0.5%/LSb] • Bits 0-7: Low ambient RH threshold (signed) [0.5%/LSb] • High threshold ≤ Low threshold: Invalid and ignored | <ul style="list-style-type: none"> • High threshold = 80% • Low threshold = 15% <p>0x 50 0F</p> | <i>rh_threshold_high</i> : <value> (unsigned/%) <i>rh_threshold_low</i> : <value> (unsigned/%) |
| 0x 3E | RH Thresholds Enabled | 1 B | Access: R/W <ul style="list-style-type: none"> • Bit 0: 0/1: Ambient RH thresholds disabled/enabled • Bits 1-7: RFU | Disabled <p>0x 00</p> | <i>rh_thresholds_enabled</i> : <value> (string/no unit) |
| 0x 40 | Accelerometer Mode | 1 B | Access: R/W <ul style="list-style-type: none"> • 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 | <ul style="list-style-type: none"> • X-axis enabled • Y-axis enabled • Z-axis enabled • Accelerometer on <p>0x 87</p> | <i>accl_mode</i> : { <i>xaxis_enabled</i> : <value>, (unsigned/no unit) <i>yaxis_enabled</i> : <value>, (unsigned/no unit) <i>zaxis_enabled</i> : <value>, (unsigned/no unit) <i>power_on</i> : <value> (unsigned/no unit) } |
| 0x 41 | Accelerometer Sensitivity | 1 B | Access: R/W <ul style="list-style-type: none"> • 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 | <ul style="list-style-type: none"> • Sample Rate = 10 Hz • Measurement Range = ±8 g <p>0x 22</p> | <i>accl_sensitivity</i> : { <i>sample_rate</i> : <value>, (unsigned/Hz) <i>measurement_range</i> : <value> (unsigned/g) } |

| Address | Name | Size | Description and Options | Default Value | JSON Variable (Type/Unit) |
|---------|---------------------------------------|------|--|--|--|
| 0x 42 | Acceleration Trigger Threshold Count | 2 B | <p>Access: R/W</p> <ul style="list-style-type: none"> Number of above-threshold acceleration samples before an acceleration trigger is registered Acceptable values: ≥ 1 0: Invalid and ignored | <p>1 trigger</p> <p>0x 00 01</p> | <p><i>accl_trigger_threshold_count: <value></i> <i>(unsigned/no unit)</i></p> |
| 0x 43 | Acceleration Trigger Threshold Period | 2 B | <p>Access: R/W</p> <ul style="list-style-type: none"> Period over which acceleration samples are counted for trigger detection [1s/LSb] Acceptable values: ≥ 5 0-4: Invalid and ignored | <p>10 seconds</p> <p>0x 00 0A</p> | <p><i>accl_trigger_threshold_period: <value></i> <i>(unsigned/s)</i></p> |
| 0x 44 | Acceleration Trigger Threshold | 2 B | <p>Access: R/W</p> <ul style="list-style-type: none"> Acceleration magnitude threshold for acceleration trigger [1 mg/LSb] | <p>2 g</p> <p>0x 07 D0</p> | <p><i>accl_trigger_threshold: <value></i> <i>(unsigned/mg)</i></p> |
| 0x 45 | Acceleration Event Grace Period | 2 B | <p>Access: R/W</p> <ul style="list-style-type: none"> Time to pass after the last accelerometer trigger before the event is cleared [1s/LSb] Acceptable values: ≥ 15 0-14: Invalid and ignored | <p>5 min</p> <p>0x 01 2C</p> | <p><i>accl_event_grace_period: <value></i> <i>(unsigned/s)</i></p> |
| 0x 46 | Acceleration Event Value to Tx | 1 B | <p>Access: R/W</p> <ul style="list-style-type: none"> Bit 0: 0/1 = Acceleration alarm UL report disabled/enabled Bit 1: 0/1 = Accelerometer Assist for geolocation disabled/enabled Bits 2-7: RFU | <ul style="list-style-type: none"> Acceleration alarm report UL enabled Accelerometer Assist enabled <p>0x 03</p> | <p><i>accl_tx: {</i> <i>accl_alarms: <value></i> <i>(unsigned/no unit)</i> <i>accl_assist: <value></i> <i>(unsigned/no unit)</i> <i>}</i></p> |
| 0x 4A | Battery Report Options | 1 B | <p>Access: R/W</p> <ul style="list-style-type: none"> 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 | <p>Remaining battery capacity [%] and remaining battery lifetime [days] reported</p> <p>0x 06</p> | <p><i>battery_tx: {</i> <i>report_capacity_enabled: <value></i> <i>(unsigned/no unit)</i> <i>report_lifetime_enabled: <value></i> <i>(unsigned/no unit)</i> <i>}</i></p> |

| Address | Name | Size | Description and Options | Default Value | JSON Variable (Type/Unit) |
|---------|-----------------------------|------|---|---|--|
| 0x 4B | Average Energy Trend Window | 1 B | <p>Access: R/W</p> <ul style="list-style-type: none"> Window size over which remaining battery lifetime is estimated [1 core tick/LSB] Acceptable values: 1, 2, ..., 255 0: Invalid and ignored | <p>10 core ticks</p> <p>0x 0A</p> | <p><i>avg_energy_trend_window: <value></i> (unsigned/no unit)</p> |
| 0x 50 | BLE Rx Mode | 1 B | <p>Access: R/W</p> <ul style="list-style-type: none"> Bits 0-6: N Number of reported devices (1–127) 0: Disables BLE Bit 7: 0/1 = Averaging mode off/on | <ul style="list-style-type: none"> Up to 8 reported devices Averaging mode on <p>0x 88</p> | <p><i>ble_mode: {</i> <i> num_reported_devices: <value></i>, <i> (unsigned/no unit)</i> <i> averaging_mode: <value></i> <i> (unsigned/no unit)</i> <i>}</i></p> |
| 0x 51 | BLE Scan Duration | 2 B | <p>Access: R/W</p> <ul style="list-style-type: none"> Bits 0-7: Scan duration [1 s/LSb] Acceptable values: 1, 2, ..., 10 0: Invalid and ignored Bits 8-15: RFU | <p>3 s</p> <p>0x 00 03</p> | <p><i>ble_scan_duration: {</i> <i> periodic: <value></i>, <i> (unsigned/no unit)</i> <i> event-based: <value></i>, <i> (unsigned/no unit)</i> <i>}</i></p> |
| 0x 52 | BLE Scan Interval | 2 B | <p>Access: R/W</p> <ul style="list-style-type: none"> Scan interval [1 ms/LSb] Acceptable values: “Scan Window”, ..., 10 000 Other values: Invalid and ignored | <p>30 ms</p> <p>0x 00 1E</p> | <p><i>ble_scan_interval: <value></i> (unsigned/sec)</p> |
| 0x 53 | BLE Scan Window | 2 B | <p>Access: R/W</p> <ul style="list-style-type: none"> Scan window [1 ms/LSb] Acceptable values: 3, ..., “Scan Interval” Other values: Invalid and ignored | <p>30 ms</p> <p>0x 00 1E</p> | <p><i>ble_scan_window: <value></i> (unsigned/sec)</p> |
| 0x 54 | Filter Range 0 | 9 B | <p>Access: R/W</p> <ul style="list-style-type: none"> Range 0 for filtered <i>BD_ADDR5</i> $B_0:B_1:B_2:B_3:B_4:B_5$ to $B_0:B_1:B_2:B_6:B_7:B_8$ <ul style="list-style-type: none"> OUI = $B_0:B_1:B_2$ LAP_{start} = $B_3:B_4:B_5$ LAP_{end} = $B_6:B_7:B_8$ | <p>Range inactive</p> <p>0x 00 00 00 00 00 00 00 00 00</p> | <p><i>filter_range_0: {</i> <i> oui: <value></i>, <i> (unsigned/no unit)</i> <i> lap_start: <value></i>, <i> (unsigned/no unit)</i> <i> lap_end: <value></i> <i> (unsigned/no unit)</i> <i>}</i></p> |

| Address | Name | Size | Description and Options | Default Value | JSON Variable (Type/Unit) |
|---------|----------------------------------|------|---|---|--|
| 0x 55 | Filter Range 1 | 9 B | <p>Access: R/W</p> <ul style="list-style-type: none"> Range 1 for filtered BD_{ADDRS} $B_0:B_1:B_2:B_3:B_4:B_5$ to $B_0:B_1:B_2:B_6:B_7:B_8$ <ul style="list-style-type: none"> OUI = $B_0:B_1:B_2$ LAP_{start} = $B_3:B_4:B_5$ LAP_{end} = $B_6:B_7:B_8$ | <p>Range inactive</p> <p>0x 00 00 00 00 00 00 00 00 00</p> | <pre>filter_range_1: { oui: <value>, (unsigned/no unit) lap_start: <value>, (unsigned/no unit) lap_end: <value> (unsigned/no unit) }</pre> |
| 0x 56 | Filter Range 2 | 9 B | <p>Access: R/W</p> <ul style="list-style-type: none"> Range 2 for filtered BD_{ADDRS} $B_0:B_1:B_2:B_3:B_4:B_5$ to $B_0:B_1:B_2:B_6:B_7:B_8$ <ul style="list-style-type: none"> OUI = $B_0:B_1:B_2$ LAP_{start} = $B_3:B_4:B_5$ LAP_{end} = $B_6:B_7:B_8$ | <p>Range inactive</p> <p>0x 00 00 00 00 00 00 00 00 00</p> | <pre>filter_range_2: { oui: <value>, (unsigned/no unit) lap_start: <value>, (unsigned/no unit) lap_end: <value> (unsigned/no unit) }</pre> |
| 0x 57 | Filter Range 3 | 9 B | <p>Access: R/W</p> <ul style="list-style-type: none"> Range 3 for filtered BD_{ADDRS} $B_0:B_1:B_2:B_3:B_4:B_5$ to $B_0:B_1:B_2:B_6:B_7:B_8$ <ul style="list-style-type: none"> OUI = $B_0:B_1:B_2$ LAP_{start} = $B_3:B_4:B_5$ LAP_{end} = $B_6:B_7:B_8$ | <p>Range inactive</p> <p>0x 00 00 00 00 00 00 00 00 00</p> | <pre>filter_range_3: { oui: <value>, (unsigned/no unit) lap_start: <value>, (unsigned/no unit) lap_end: <value> (unsigned/no unit) }</pre> |
| 0x 58 | BLE Advertising Enable / Disable | 1 B | <p>Access: R/W</p> <ul style="list-style-type: none"> Bits 7-1: Ignored Bit 0: 0/1 = Advertising disabled/enabled | <p>Advertising disabled</p> <p>0x 00</p> | <pre>advertising_enabled: <value> (unsigned/no unit)</pre> |
| 0x 59 | BLE Advertising Interval | 2 B | <p>Access: R/W</p> <ul style="list-style-type: none"> Advertising interval [1 ms/LSb] Acceptable values: 100 ms – 10240 ms Other values: Invalid and ignored | <p>100 ms</p> <p>0x 00 64</p> | <pre>min_advertising_interval: <value> (unsigned/ms)</pre> |

| Address | Name | Size | Description and Options | Default Value | JSON Variable (Type/Unit) |
|---------|---------------------------------|------|--|---|--|
| 0x 5B | BLE Tx Advertising Power | 1 B | <p>Access: R/W</p> <ul style="list-style-type: none"> BLE Tx Power [dBm] <ul style="list-style-type: none"> 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 | <p>0 dBm</p> <p>0x 00</p> | <p><i>tx_advertising_power: <value></i> <i>(unsigned/no unit)</i></p> |
| 0x 5C | BLE Advertisement Packet Format | 1 B | <p>Access: R/W</p> <ul style="list-style-type: none"> 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 | <ul style="list-style-type: none"> iBeacon enabled Eddystone UID disabled Eddystone TLM disabled <p>0x 01</p> | <p><i>advertising_packet_format: {</i> <i> ibeacon: <value></i> <i> (eddystone/no unit)</i> <i> eddystone_uid: <value></i> <i> (eddystone/no unit)</i> <i> eddystone_tlm: <value></i> <i> (eddystone/no unit)</i> <i>}</i></p> |
| 0x 5F | BLE MAC Address | 6 B | <p>Access: RO</p> <p>The 6-Byte BLE Device MAC address, <i>BD_ADDR</i>, of the sensor.</p> | Unique for every sensor | <p><i>mac_address: <value></i> <i>(unsigned/no unit)</i></p> |
| 0x 70 | Flash Write Command | 2 B | <p>Access: X</p> <ul style="list-style-type: none"> 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: Ignored | N/A | <p><i>write_to_flash {</i> <i> app_config: <value></i> <i> (unsigned/no unit)</i> <i> lora_config: <value></i> <i> (unsigned/no unit)</i> <i> restart_sensor: <value></i> <i> (unsigned/no unit)</i> <i>}</i></p> |

| Address | Name | Size | Description and Options | Default Value | JSON Variable (Type/Unit) |
|---------|---|------|---|---------------|--|
| 0x 71 | FW Metadata | 7 B | <ul style="list-style-type: none"> • 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 number²⁷ | N/A | <pre> 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) } </pre> |
| 0x 72 | Reset Configuration to Factory Defaults | 1 B | <p>Access: X</p> <ul style="list-style-type: none"> • 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 | <pre> config_factory_reset { app_config: <value>, (unsigned/no unit) loramac_config: <value> (unsigned/no unit) } </pre> |
| 0x 73 | BLE Metadata | 6 B | <p>Access: RO</p> <ul style="list-style-type: none"> • 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 | <pre> ble_metadata { stack_ver_major: <value>, (unsigned/no unit) stack_ver_minor: <value>, (unsigned/no unit) stack_ver_revision: <value>, (unsigned/no unit) } </pre> |

²⁷ Defined by Table 5-7.

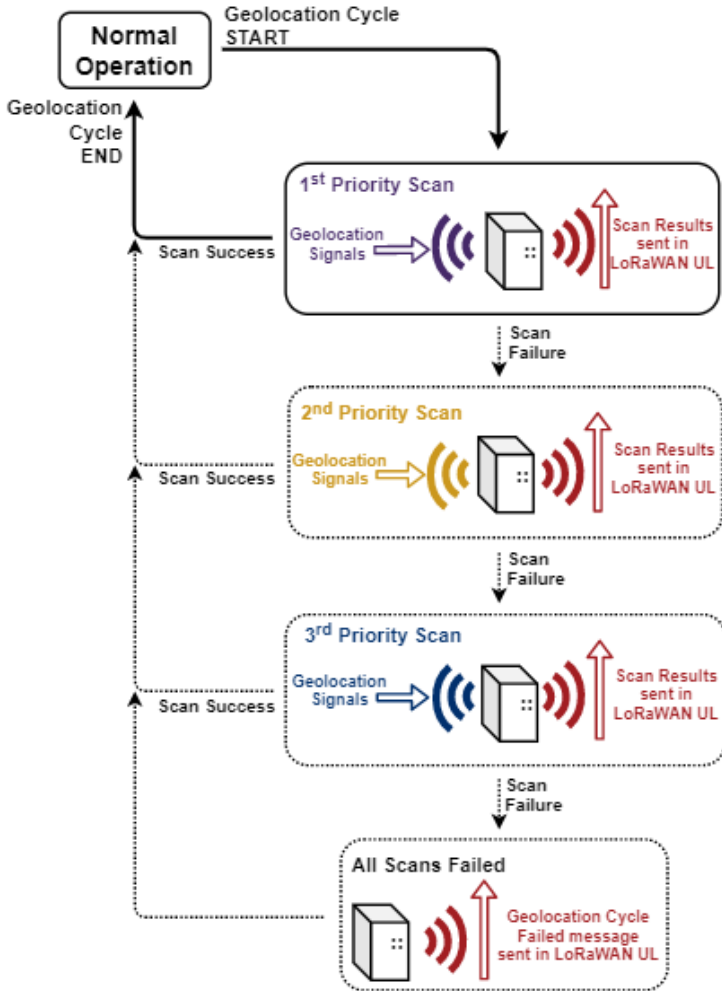
Table 0-4: Comparison of Default Configuration Values for Tracker and Beacon Mode

| 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 | |
| LoRaMAC Rx2 Window | 13 | As per Table 5-2 | | |
| 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 Accelerometer | 24 | 00 00 | 00 00 | |
| Ticks per Temperature | 25 | 00 3C | 00 3C | |
| Ticks per Relative Humidity | 26 | 00 3C | 00 3C | |
| Geolocation Strategy | 30 | 1B | 1B | Geolocation and GNSS |
| GNSS Diagnostics Value to Tx | 32 | 00 | 00 | |
| Clock Sync Configuration | 33 | C7 | C7 | |
| Almanac Update Request Period | 34 | 00 1E | 00 1E | |
| Almanac Update Check Period | 35 | 01 | 01 | |
| Assist Coordinates | 36 | 00 00 00 00 00 00 00 00 00 | 00 00 00 00 00 00 00 00 00 | |
| GNSS Satellite Constellation Option | 37 | 02 | 02 | |
| Default GNSS Scan Mode | 38 | 01 | 01 | Ambient Environment Sensing |
| Temperature/RH Sample Period: Idle | 39 | 00 00 00 3C | 00 00 00 3C | |
| Temperature/RH Sample Period: Active | 3A | 00 00 00 1E | 00 00 00 1E | |
| Low/High Temperature Thresholds | 3B | 1E 0F | 1E 0F | |
| Temperature Thresholds Enabled | 3C | 00 | 00 | |
| Low/High RH Thresholds | 3D | 50 0F | 50 0F | |
| RH Thresholds Enabled | 3E | 00 | 00 | Accelerometer |
| Accelerometer Mode | 40 | 87 | 07 | |
| 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 Management |
| Battery Report Options | 4A | 06 | 06 | |
| Average Energy Trend Window | 4B | 0A | 0A | BLE Scanning (Tracker Mode) |
| Mode | 50 | 88 | 88 | |
| Scan Duration | 51 | 00 03 | 00 03 | |
| Scan Interval | 52 | 00 1E | 00 1E | |
| Scan Window | 53 | 00 1E | 00 1E | |

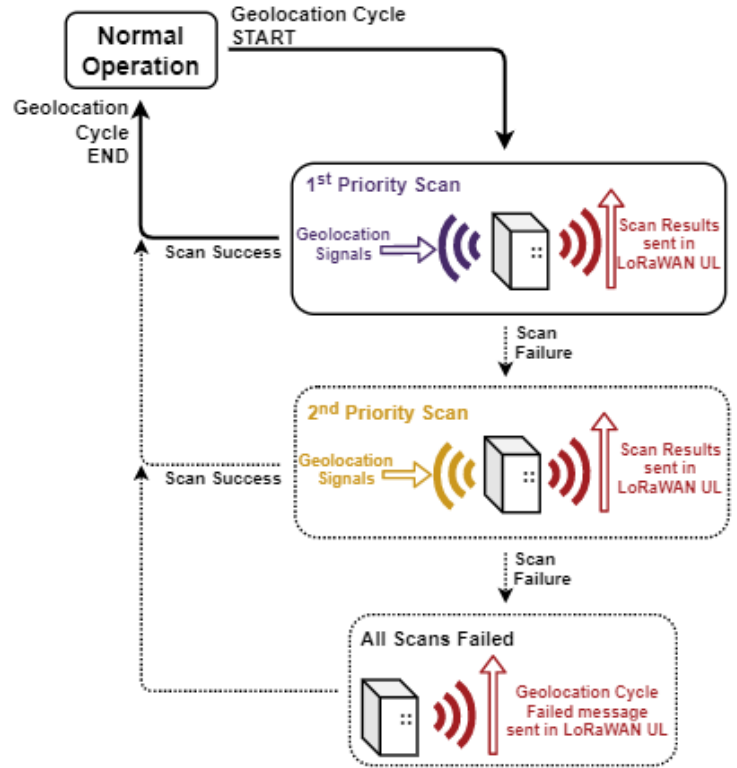
| Name | Register Address [Hex] | Default Value, Tracker Mode [Hex] | Default Value, Beacon Mode [Hex] | Category |
|------------------------------|------------------------|-----------------------------------|----------------------------------|-------------------------------|
| Filter Range 0 | 54 | 00 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 00 | |
| Filter Range 2 | 56 | 00 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 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 | | |

Appendix 3 – List of Geolocation Strategies

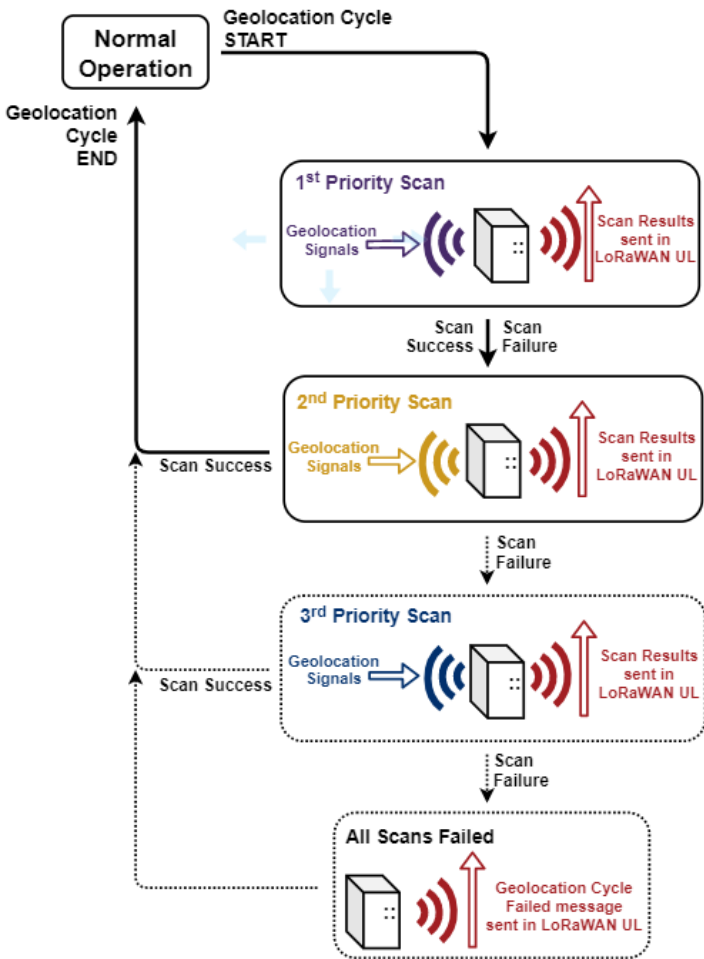
Geolocation Strategy 1 Fallback, All Scans Defined



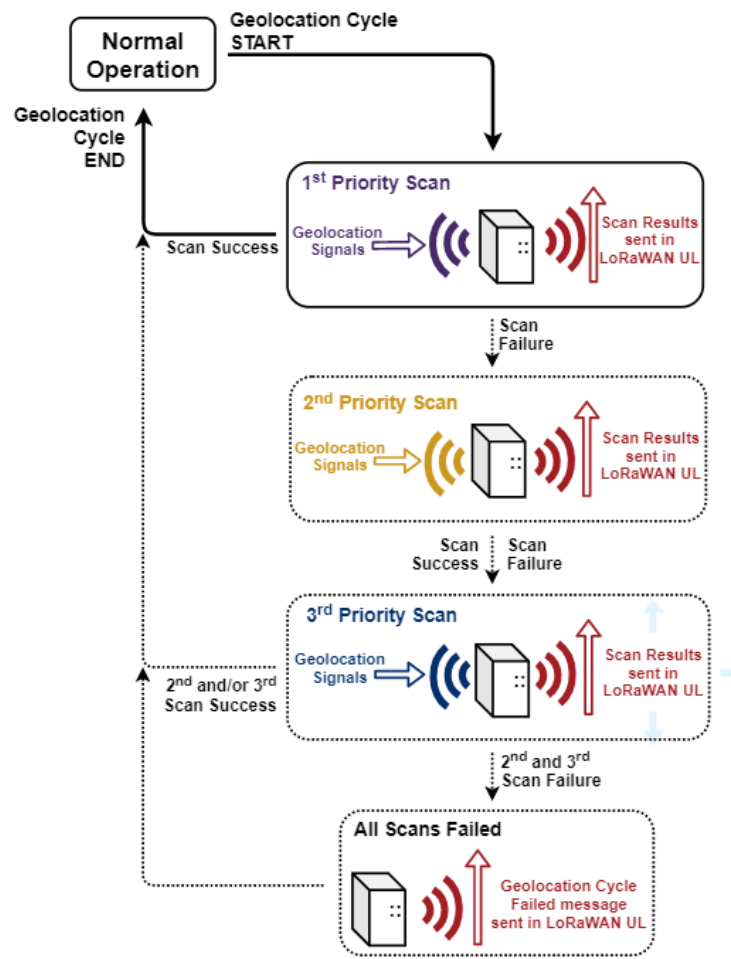
Geolocation Strategy 2 Fallback, 2 Scans Defined



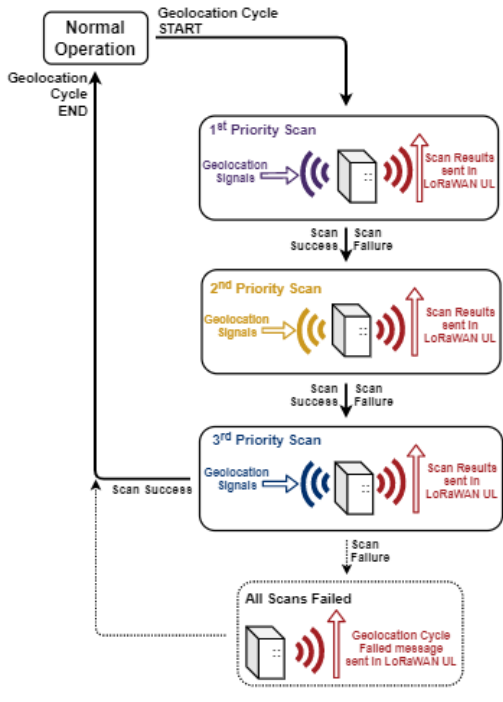
Geolocation Strategy 3 Backup 1, All Scans Defined



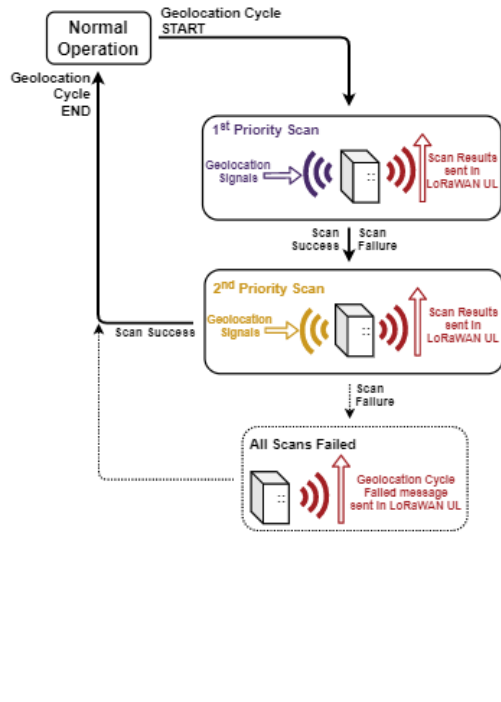
Geolocation Strategy 4 Backup 2, All Scans Defined



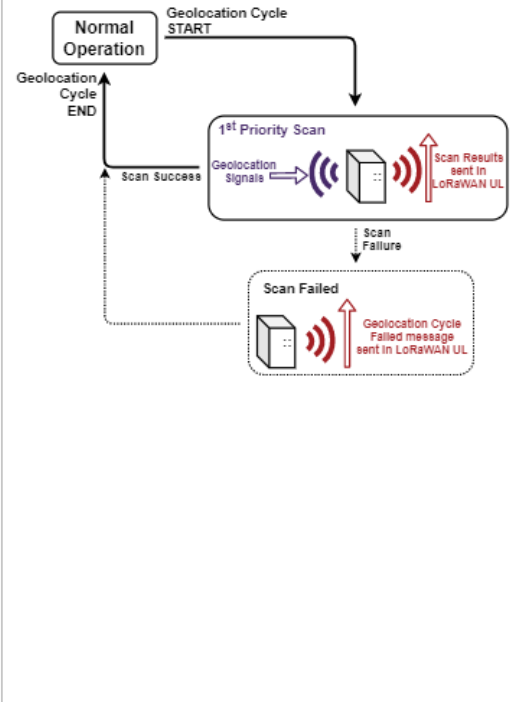
Geolocation Strategy 5
All Scans, All Scans Defined



Geolocation Strategy 6
All Scans, 2 Scans Defined



Geolocation Strategy 7
All Scans, 1 Scan Defined



References

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