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SPARROW | PELICAN

Enterprise Asset Tracker & BLE Beacon

Technical Reference Manual

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Revision History

TRM Version	Date	Editor	HW Generation: FW Version	Comments
0.1	June 14, 2021	Carter Mudryk	Gen1: 1.0.15 Gen2: 1.0.15	• Initial release based on BLE Tracker TRM T0005946_TRM_v0.11. • Includes new averaging mode.
1.0	June 30, 2021	Carter Mudryk	Gen1: 1.0.15 Gen2: 1.0.15	• Added missing register description sections. • Updated description of filtering packet encoding and decoding for clarity. • Updated to more recently battery life estimates. • Updated List of Acronyms. • Added PCBA T-codes to product code table. • Added DL information stream on port 99 information and added section on how to put the device to sleep OTA. • Minor grammatical changes.
1.1	July 5, 2021	Carter Mudryk	Gen1: 1.0.16 Gen2: 1.0.16	• Added order codes/LoRaWAN regions table. • Removed magnetic pattern operational state description. • Minor error and formatting corrections.
2.0	November 17, 2021	Carter Mudryk	Gen2: 2.0.10	• Added information on new Beacon capabilities. • Added information on new coulomb counting function.
2.1	February 15, 2022	Carter Mudryk	Gen2: 2.0.12	• Corrected product T-Codes. • Changed BLE advertising frequency to 1 register. • Corrected maximum advertising interval to 40 000 ms. • Added list of all registers to Appendix. • Minor corrections based on feedback. • Changed default value of register
2.2	March 31, 2022	Carter Mudryk	Gen2: 2.0.13	Changed default value of register 0x 4A for Beacon mode.
2.3	April 12, 2022	Carter Mudryk	Gen2: 2.0.13	Corrected default values in Table 6-5.
2.4	April 21, 2022	Carter Mudryk	Gen2: 2.0.14	• Added “B” in document title to reflect Beacon mode functionality. • Added anti-brick functional description in Section 5.2.1.1.

TRM Version	Date	Editor	HW Generation: FW Version	Comments
2.5	April 22, 2022	Carter Mudryk	Gen2: 2.0.14 Gen2.5: 3.0.0	• Changed and clarified terminology: ○ "Tracker" = specifically when referring to the device operating in Tracker mode. ○ "Beacon" = specifically when referring to the device operating in Beacon mode. ○ "Sensor" = when referring to the general functions not specific to either Tracker or Beacon mode. • Removed references to the sensor config web app. • Added description of periodic and event-based reporting in Section 2. • Minor formatting, grammatical, and clarifying changes throughout.
2.6	July 20, 2022	Carter Mudryk	Gen2: 2.0.16 Gen2.5: 3.0.5	• Minor grammatical corrections. • Moved FW versioning notes to Revision History table. • Updated product name terminology to "PELICAN" and "SPARROW." • Changed default value of register 0x 40 (in Tracker mode only) to 0x 87 to reflect that the accelerometer should be enabled by default. • Moved operational description of the accelerometer to new section and added detail for clarity. • Added function for generating an event-based BLE report upon accelerometer clear.
2.7	August 3, 2022	Carter Mudryk	Gen2: 2.0.16 Gen2.5: 3.0.6	Changed default value of register 0x 11 to enable ADR by default.

TRM Version	Date	Editor	HW Generation: FW Version	Comments
2.8	December 12, 2022	Carter Mudryk	Gen2: 2.0.20 Gen2.5: 3.0.16	• Added information about differences between generations. • Changed document name to reflect marketing names. • Updated Gen2.5 T-codes. • Added description of what happens in the case of a delayed BLE scan report in Sections 0 and **Error! Reference source not found.**. • Corrected and clarified LED pattern descriptions. • Indicated deprecation of battery voltage reporting for Gen2.5 devices. • Updated descriptions for battery management and gauging. • Changed default value of register 0x 2A in Beacon mode to allow a battery report upon button press. • Changed default value of register 0x 4A to allow battery reporting format to be both remaining capacity [%] and remaining lifetime [days] by default for both Tracker and Beacon Mode. • Added register 0x 4B to reflect new remaining battery lifetime system design. • Changed limit on acceptable values for register 0x 59. • Corrected and updated options for Beacon Tx power in register 0x 5B for Gen2 and Gen2.5 devices. • Updated description for Eddystone TLM battery data to be clear on Gen2 vs Gen2.5 behaviour. • Minor grammatical fixes.

TRM Version	Date	Editor	HW Generation: FW Version	Comments
2.9	April 19, 2023	Carter Mudryk	Gen2: 2.0.22 Gen2.5: 3.2.4	• Added row to Table 1-3 to reflect that accelerometer events and clears also trigger event-based BLE scans by default. • Added register 0x 46 to Table 6-5 as one of the settings that changes depending on whether the Sensor is in Tracker or Beacon mode. • Changed default value of register 0x 12. • Removed MCU temperature threshold-based reporting support. • Minor grammatical and formatting fixes.
3.0	October 19, 2023	Carter Mudryk	Gen2.5: 3.2.4	• Separated all info relating to PELICAN Ex and other Gen2 variants into separate TRM. • Changed order of sections so that document structure reflects function instead of stream direction.

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List of Acronyms

ABP .... Activation By Personalization
ADR..... .... Adaptive Data Rate
AS........ .... Asia
ATEX.... .... Atmosphere Explosible
AU .... Australia
B.......... .... Byte
BD_ADDR......... Bluetooth Device Address
BLE .... Bluetooth Low Energy
CRC...... .... Cyclic Redundancy Check
DC .... Direct Current
DL........ .... DownLink
DR .... Data Rate
EAT...... .... Enterprise Asset Tracker
EIRP..... .... Equivalent Isotropically Radiated Power
EoS .... End of Service
EU .... European Union
FW....... .... FirmWare
g .... gravity (unit of acceleration)
HW...... .... HardWare
ID .... Identity/Identifier
IN .... India
IoT....... .... Internet of Things
IP......... .... Ingress Protection
JSON.... .... JavaScript Object Notation
KR........ .... KoRea
LAP...... .... Lower Address Part
LED...... .... Light-Emitting Diode
LoRa .... Long Range
LoRAMAC......... LoRaWAN MAC
LoRaWAN .... LoRa Wide Area Network
LoS....... .... Line-of-Sight
LSb....... .... Least Significant bit
LSB....... .... Least Significant Byte
LTC....... .... Lithium Thionyl Chloride
MAC .... Medium Access Control
MCU .... MicroController Unit
MSb..... .... Most Significant Bit
MSB..... .... Most Significant Byte
NA .... North America
NS........ .... Network Server
OTA .... Over-The-Air
OTAA... .... OTA Activation
PCBA.... .... Printed Circuit Board Assembly
OUI .... Organizationally-Unique Identifier
POST.... .... Power-On Self-Test
RF .... Radio Frequency
RO .... Read-Only
RTLS..... .... Real-Time Location System
R/W..... .... Read/Write
RSSI .... Received Signal Strength Indicator
Rx .... Receiver / Receive
sec .... second(s)
SW....... .... SoftWare
TLM .... TeLeMetry
TRM..... .... Technical Reference Manual
Tx......... .... Transmitter / Transmit
UL .... UpLink
v. .... version
ver. .... Version

1 Overview

> **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 §5.5.4.

This document contains the technical information about the supported functionality of the TEKTELIC *Enterprise Asset Tracker* sensors, which include the SPARROW and PELICAN. 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.

The Enterprise Asset Tracker is a BLE-capable LoRaWAN IoT sensor run on a single LTC battery and packed into a compact polycarbonate casing. The device's primary purpose is to scan for and report nearby BLE peripherals (devices) up to the LoS range of 70 m. Some common applications include, but are not limited to:

- Asset tracking within a network of BLE beacon devices,
- Proximity detection for equipment in places of interest, and
- Asset movement detection and security.

The sensor can also be configured to act as a BLE beacon. When configured this way, the device no longer conducts scans (Rx), but instead sends out advertisements (Tx) which make it discoverable by other nearby trackers or BLE-capable devices.

The sensor is also equipped with a multipurpose accelerometer. It can generate alarm messages based on configurable thresholds, trigger extra BLE scans when motion is detected and cleared, and report the acceleration vector periodically if knowledge of sensor orientation is of interest.

Additional sensing functions on the sensor include on-board MCU temperature and the remaining battery capacity/lifetime. The battery lifetime of the sensor has been estimated to be up to:

- 5.5 years for SPARROW operating with default Tracker mode settings[1].
- 15+ years for PELICAN operating with default Tracker mode settings[1].

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[1] Default settings plus 24 event-based BLE scans and reports per day, operating at DR2. Applicable to NA region only.

- 16 months for SPARROW operating with default Beacon mode settings[2].
- 4.5 years for PELICAN operating with default Beacon mode settings[2].

The SPARROW has an externally accessible push-button that can be configured to have various functions. The PELICAN has a magnetic switch which is used to wake the device from the DEEP SLEEP state (used for shipping) and to force ULs when the device is active.

There have been 3 *generations* of the BLE Sensors: Gen1, Gen2, and Gen2.5. Note that Gen1 and Gen2 functional descriptions are outside the scope of this TRM version; for Gen1 or Gen2 sensors, please refer to an older document version in accordance with your device as described in the Revision History Table.

Table 1-1: Generational Differences

Generation	MCU	FW Versions	Supported Models
Gen1	Silicon Labs EFR32 Blue Gecko	• 1.x.x (does not support *beacon mode*)	• SPARROW
Gen2	Silicon Labs EFR32 Blue Gecko	• 1.x.x (does not support *beacon mode*) • 2.x.x (supports *beacon mode*)	• SPARROW • PELICAN • PELICAN EX
Gen2.5	STM 32	3.x.x	• SPARROW • PELICAN

Table 1-2 presents the currently available Sensor HW variants. The information streams supported by the SW have been shown in Table 1-3, and the default configuration for reporting data has been shown in Table 1-4.

Table 1-2: Enterprise Asset Tracker HW Models

Product Code, Module-Level T-Code	Product Code, PCBA-Level T-Code	Model Name	Description	Battery/Enclosure Size
T0007128	T0008265	SPARROW	Enterprise Asset Tracker (Indoor), Wall-Mount	AA-cell
T0006906	T0008176	PELICAN	Enterprise Asset Tracker (Outdoor), Wall-Mount	C-cell

[2] Default settings with no event-based reports, operating at DR2. Applicable to NA region only.

Table 1-3: Enterprise Asset Tracker Information Streams

Stream Direction	Data Type	Sent on LoRaWAN Port [decimal]
UL (Tracker to NS)	Sensor data from the MCU, battery gauge, and accelerometer	**10**
	Report of discovered BLE devices	**25**
	Responses to Configuration and Control Commands	**100**
DL (NS to Tracker)	Putting Tracker into DEEP SLEEP	**99**
	Configuration and Control Commands	**100**

Table 1-4: Enterprise Asset Tracker Default Reporting Behavior

Report	Report Type	Default Periodicity
Battery status	Periodic	24 hours
	Event-based	Each time the magnetic switch is triggered (C-cell variants only)
Discovered BLE devices (up to 8) with averaged RSSIs after scanning for 3 sec	Periodic	1 hour
Discovered BLE devices (up to 8) with averaged RSSIs after scanning for 1 sec	Event-based	Each time the function button is pressed (AA-cell variants only)
		Each time above-threshold motion is detected and each time motion stops
Acceleration vector	Periodic	Disabled
Accelerometer motion alarm	Event-based	Each time above-threshold motion is detected and each time motion stops
MCU temperature	Periodic	Disabled

The following subsections provide a more detailed description of the functionality of each of the subsystems and user interfaces available on the sensor.

2 Magnetic Function

Only the PELICAN is equipped with magnetic functionality; the information in this section is not applicable to SPARROW.

The PELICAN 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 right above the magnet symbol on the endcap, as shown in Figure 2-1.

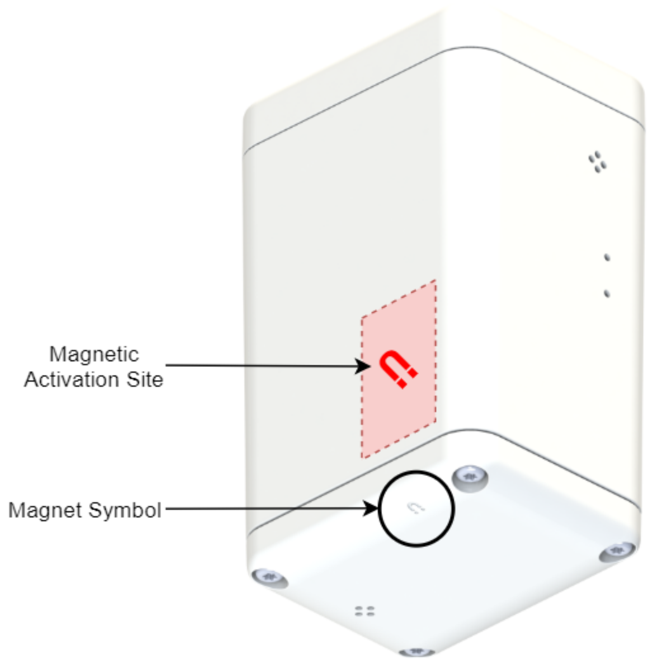


Figure 2-1: Enclosure View Showing Magnetic Activation Site and Symbol

There are 3 main magnetic functions of the PELICAN:

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

2.1 DEEP SLEEP

2.1.1 Sensor Activation

When a PELICAN 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*[3].

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.

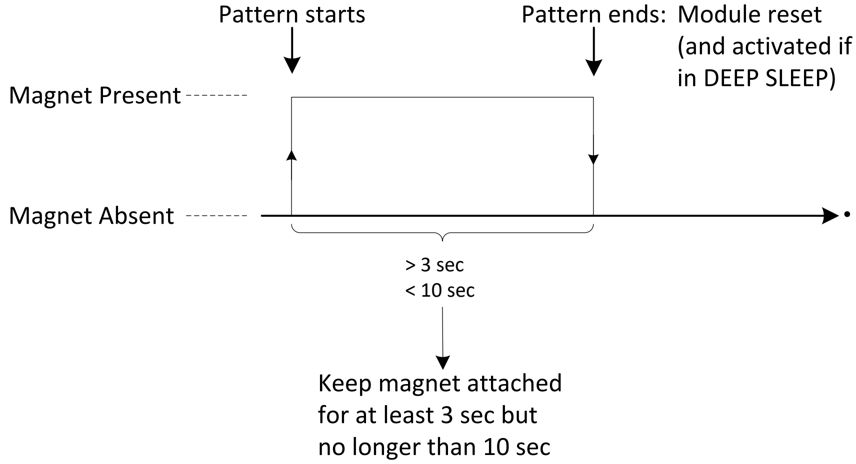


Figure 2-2: The Magnetic Activation/Reset Pattern.

When the magnetic activation/reset pattern is applied to the sensor it displays an LED indication (described in §3.2.3) 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 network[4].

2.1.2 Re-entering DEEP SLEEP

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

---

[3] The SPARROW does not support DEEP SLEEP mode nor any magnetic function. A SPARROW is activated simply by the removal of the battery tab [6].

[4] 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 §5.4.1.2 for details.

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***.

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.

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 (LoRa Alliance, Inc., 2016). 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.

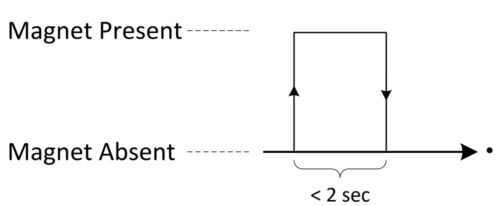


Figure 2-3: The Magnetic Forced UL Pattern

The magnetic forced UL has a payload which contains a regular battery report on ***LoRaWAN port 10***, as described in §4.1.1.

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 PELICAN and SPARROW enclosures are shown in Figure 3-1 and the locations of the external user interfacing are identified. The reset button and LED behaviour are described in the following subsections. Refer to §8 for function button behaviour.

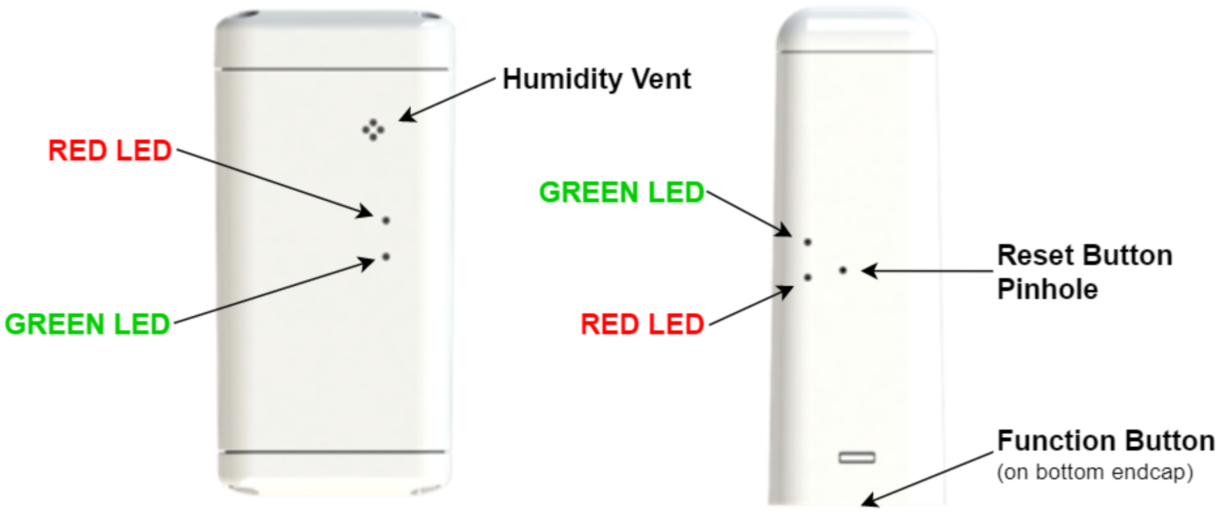


Figure 3-1: External User Interfacing on PELICAN (left) and SPARROW (right) Enclosures

3.1 Reset Button

Only the SPARROW has a physical reset button. To reset a PELICAN, a magnet must be used as described in §2.2.

To reset the SPARROW, insert a pin or paperclip into the reset button pinhole at the location shown in Figure 3-1. Press firmly until the button is pressed, then release. As soon as the button is released, the SPARROW will reset and begin the network join process. The LEDs will indicate the reset as described in §3.2.1.

3.2 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 single **RED** flash every 10 s	JOIN mode; attempting to join the network
Single **RED** flash	UL sent
Single **GREEN** flash	DL received
3 **GREEN** flashes	Waking from DEEP SLEEP
3 **RED** flashes	Entering DEEP SLEEP

3.2.1 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.

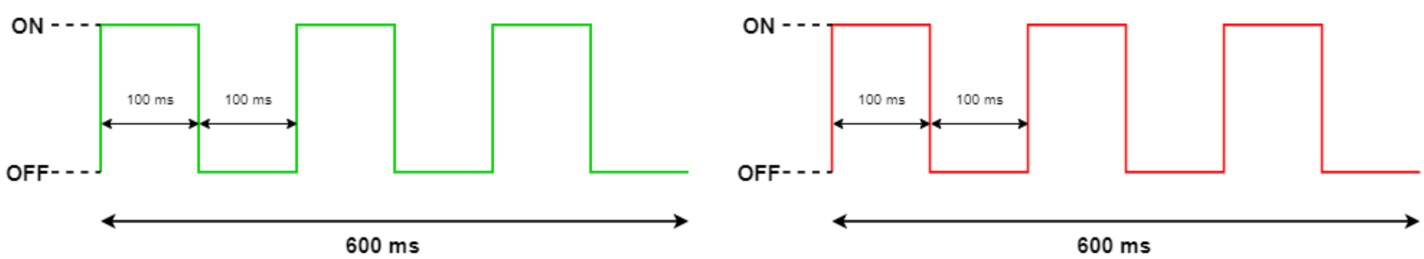


Figure 3-2: The GREEN POST Pass (left) and RED POST Failure (right) LED Patterns

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 hour[5]:
    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 10 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 (LoRa Alliance, Feb 2017).
        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

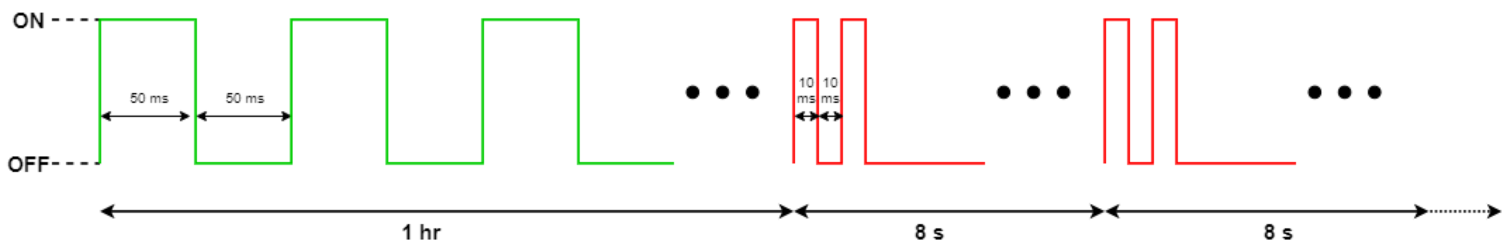


Figure 3-3: The LED Patterns During JOIN Mode

3.2.2 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.

[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 §5.4.1.2 for details.

b. **GREEN** flashes just once with a pulse duration of 100 ms right after receiving a downlink.

3.2.3 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 §3.2.1 occur.

There is another LED pattern for when the device is put back into DEEP SLEEP. The following LED pattern is displayed about 3 sec 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 §3.2.1 occur.
2. Immediately, **RED** is toggled ON and OFF 3 times: every 100 sec for 0.6 sec as shown in Figure 3-4.

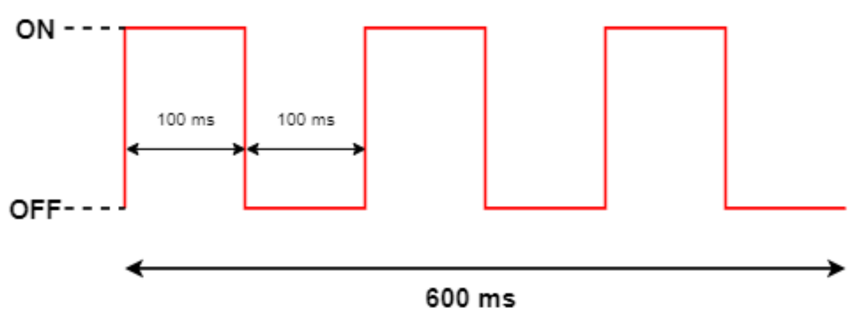


Figure 3-4: The RED LED Pattern Before Entering DEEP SLEEP

4 General LoRaWAN Payload Formats and Configuration Settings

As Class A LoRaWAN end-devices, the SPARROW and PELICAN communicate with the NS using LoRaWAN packets (LoRa Alliance, Inc., 2016). The communication behaviour as well as other device-level behaviour is configurable through SW settings. The following subsections describe the communication streams, packet formats, and configuration settings supported by the SPARROW and PELICAN.

There is an online application called *KONA ATLAS* available as a comprehensive packet codec tool (TEKTELIC Communications Inc., 2023). It supports encoding DL payloads and decoding UL payloads for SPARROW and PELICAN.

4.1 UL Payload Formats

UpLinks (ULs) are LoRaWAN packets sent from the sensor to the NS. They are used for the following purposes in SPARROW/PELICAN[6]:

1. **Reports** containing real time sensor data.
2. **Responses** to configuration and control commands[7].

Each UL is sent on the appropriate upstream port. The UL streams supported by the SPARROW/PELICAN SW are shown in Table 4-1.

Table 4-1: UL Information Streams

Data Type	Sent on *LoRaWAN Port* [decimal]
Reports containing sensor data from the MCU, battery, accelerometer, and/or function button	**10**
Reports containing discovered BLE device data	**25**
Responses to configuration and control commands	**100**

4.1.1 *LoRaWAN Port 10* and *LoRaWAN Port 25* ULs: Sensor Data Reports

All sensor data report ULs sent on ***LoRaWAN port 10*** and ***LoRaWAN port 25*** 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 outside of the periodic reporting schedule. These external events include function button presses, magnetic switch actuation, and motion of the device above the accelerometer threshold. 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
- Battery voltage[8]
- Acceleration alarm
- Acceleration vector
- MCU Temperature

[6] Here "ULs" means "SW application-level ULs;" there are other MAC-level 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].

[7] See §4.2.2 for a description of configuration and control commands.

[8] Battery voltage reporting is no longer supported on Gen2.5 devices. See Table 1-1 for determining generation.

The ***LoRaWAN port 10*** UL report payload is encoded in a general frame format shown in Figure 4-1. A big-endian format (MSb/MSB first) is always followed. The specific data channels, data types, and data encoding definitions are described in §0 (battery data), §7 (accelerometer data), and §0 (MCU data). For a complete summary list, refer to Appendix 2 – List of Sensor Data Report UL Frame Formats.

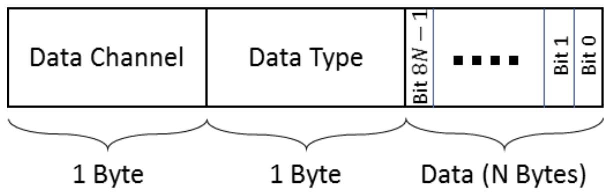


Figure 4-1: The UL Frame Format for a Sensor Data Report

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

Discovered BLE device data is sent in reports on ***LoRaWAN port 25***. BLE reporting payload structures differ from other sensor data formats described above. See §6 for a complete description of BLE operation and reporting behaviour.

4.1.2 *LoRaWAN Port 100* ULs: Responses to Commands

The sensor sends ULs on ***LoRaWAN port 100*** in response to DLs received which contain configuration and control commands[9]. These UL responses include:

- **Read response**: returning the value of a configuration register in response to a query from a DL read command block.
- **Write response**: Returning an acknowledgement after a successful reconfiguration of a register(s) through a DL write command block.

In the former case, the sensor responds with the addresses and values of each of the registers under inquiry (this can be in one or more consecutive UL packets depending on the maximum frame payload size allowed at the current data rate (LoRa Alliance, Feb 2017)). The bit indexing scheme is as shown in Figure 4-2.

In the latter case, the sensor responds with a 4-Byte CRC32 of the entire DL payload (which may be a combination of read and write commands) as the first 4 bytes of the UL frame. If the DL

[9] See §4.2.2 for a description of configuration and control commands.

payload has also had read commands, the 4 CRC32 bytes are followed by the address and value of each of the registers under inquiry (like the sensor response in the former case).

4.1.2.1 Example UL Payloads

- **0x 20 00 00 00 3C 21 00 01**
    - 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

- **0x 81 03 E8 5B**
    - 4B CRC in response to a write command DL

4.2 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 SPARROW/PELICAN[10]:

1. To read the current configuration settings of the sensor.
2. To change the current configuration settings of the sensor.
3. To cause the sensor to perform an operation, such as reset or enter DEEP SLEEP.

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 4-2.

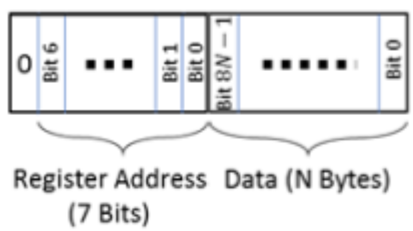


Figure 4-2: Bit Indexing Scheme for Configuration Registers

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 §4.2.1.

Each DL must be sent on the appropriate downstream port. The DL streams supported by the SPARROW/PELICAN 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	**99**
Configuration and Control Commands	**100**

[10] Here "DLs" means "SW application-level DLs;" there are other MAC-level 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].

4.2.1 *LoRaWAN Port 99* DLs: Entering DEEP SLEEP

Only the PELICAN supports DEEP SLEEP mode.

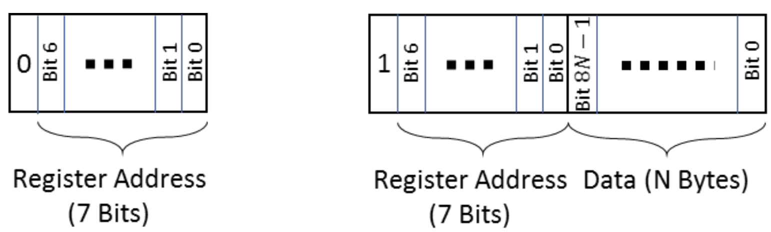
A DL can be sent to remotely put the PELICAN into DEEP SLEEP mode. The frame payload must contain the single byte **0x 00** and the DL must be sent on ***LoRaWAN port 99***.

See §2.1 for more information about DEEP SLEEP.

4.2.2 *LoRaWAN Port 100* DLs: Configuration and Control Commands

All DL configuration and control commands are sent on ***LoRaWAN port 100***.

A single DL configuration and control message can contain multiple command blocks, with a possible mix of read, write, and executable commands. Each message block is formatted as shown in Figure 4-3. A big-endian format (MSb/MSB first) is always followed.



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

Figure 4-3: 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 4-3.

- **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.

Some general examples of configuration and control DL payloads are listed in §4.2.2.1. The specific definitions, sizes, default values, and example payloads of all configuration registers are described in the following sections, which are organized by function:

- LoRaMAC|§0
- Periodic Reporting|§5.1.2.1
- MCU Temperature|§0
- Battery Management|§0
- General Command and Control Operations|§5.4.3.5
- BLE Tracker|§0
- BLE Beacon|§⍰o⍰
- Accelerometer|§7
- Function Button|§8

For a complete summary list of all registers, see Appendix 1 – List of Configuration Registers and Default Values.

4.2.2.1 Example DL Payloads

- Read registers 0x 10, 0x 11, and 0x 12:
    - DL payload: **0x 10 11 12**
        - Register 0x 10 with bit 7 set to 0 = 0x 10
        - Register 0x 11 with bit 7 set to 0 = 0x 11
        - Register 0x 12 with bit 7 set to 0 = 0x 12

- Read register 0x 13 and write value 0x 80 00 to register 0x 10:
    - DL payload: **0x 13 90 80 00**
        - Register 0x 13 with bit 7 set to 0 = 0x 13
        - Register 0x 10 with bit 7 set to 1 = 0x 90
        - Value 0x 80 00

5 Basic Operation

The basic functionality of the SPARROW and PELICAN can be broken down into the following categories:

- **LoRaMAC Options**: LoRaWAN general parameters and behaviour as defined by the LoRaWAN Specifications (LoRa Alliance, Inc., 2016).
- **Periodic Report Scheduling**: Scheme for scheduling regular sensor data reports.
- **MCU Data Reporting**: Reporting the MCU temperature.
- **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 (LoRa Alliance, Inc., 2016), (LoRa Alliance, Feb 2017). 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 4-2. To access these registers, a command must be formatted and sent according to the details described in §4.2.2.

Table 5-1: LoRaMAC Options Configuration Registers

Address	Name	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 10	Join Mode	2 B	Access: R/W • Bit 15: 0/1 = ABP/OTAA mode • Bits 0-14: Ignored	OTAA mode **0x 80 00**	*loramac_join_mode: <value> (unsigned/no unit)*
0x 11	Options	2 B	Access: R/W (bit 1 is RO) • Bit 0: 0/1 = Unconfirmed/Confirmed UL • Bit 1 = 1 (RO): 0/1 = Private/Public Sync Word • Bit 2: 0/1 = Duty Cycle disabled/enabled[11] • Bit 3: 0/1 = Disable/Enable ADR • Bits 4-15: Ignored	• Unconfirmed UL • Public Sync Word • Duty cycle enabled[11] • ADR enabled **0x 00 0E**	*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) }*

[11] WARNING: Disabling the duty cycle in certain regions makes the sensor non-compliant with the LoRaWAN Specifications [1]. It is recommended that the duty cycle remains enabled. In the LoRa RF regions where there is no duty cycle limitation, the "enabled duty cycle" configuration is ignored.

Address	Name	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 12	DR and Tx Power[12]	2 B	Access: R/W • Bits 8-11: Default DR number • Bits 0-3: Default Tx power number • Bits 4-7, 12-15: Ignored	• DR0 • Tx Power 0 (max power; see Table 5-2) **0x 04 00**	*loramac_dr_tx {* *dr_number: <value>,* *(unsigned/no unit)* *tx_power_number:* *<value>* *(unsigned/no unit)* *}*
0x 13	Rx2 Window	5 B	Access: R/W • Bits 8-39: Channel frequency in Hz for Rx2 • Bits 0-7: DR for Rx2	As per Table 5-2**Error! Reference source not found.**	*loramac_rx2 {* *frequency: <value>,* *(unsigned/Hz)* *dr_number: <value>* *(unsigned/no unit)* *}*

Table 5-2: Default Max Tx Power, Rx2 Channel Frequency, and Rx 2 DR Number by Regions

RF Region	Max Tx EIRP[13] [dBm]	Channel Frequency for Rx2 Window [Hz]	DR Number for Rx2 Window
EU868	16	869525000	0
US915	30	923300000	8
AS923	16	923200000	2
AU915	30	923300000	8
IN865	30	866550000	2
KR920	14	921900000	0
RU864	16	869100000	0

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.

[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].

[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.

5.1.2.1 Example DL Payloads

- Switch Device to ABP Mode:
    - DL payload: **0x 90 00 00**
        - Register 0x 10 with bit 7 set to 1 = 0x 90
        - Desired option: register value with bit 15 set to 0 = 0x 00 00

- 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 the current Rx2 settings:
    - DL payload: **0x 92 03 04 13**
        - Register 0x 12 with bit 7 set to 0 = 0x 92
        - DR3 = 0x 03
        - Tx 4 = 0x 04
        - Register 0x 13 with bit 7 set to 0 = 0x 13

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:

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

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

- **Battery**: Remaining capacity [%], remaining lifetime [days], voltage [mV][14], or any combination. See §5.3.3.1 for battery management details.
- **Accelerometer**: Acceleration vector [*g*]. See §7 for accelerometer operation details.
- **BLE Scan**: Discovered BLE device MAC addresses and RSSIs [dBm]. See §0 for BLE scanning and reporting details.
- **MCU Temperature**: Temperature of the MCU [°C]. See §5.3 for MCU data reporting details.

If <Data Type> *Reporting Period* equals 0, it means that periodic reporting is disabled for that data type. This happens when either the *Seconds per Core Tick* or *Ticks per* <Data Type> is equal to 0. To disable the periodic reporting of a specific data type, set its *Ticks per* <Data Type> to 0. To disable all periodic reporting, set *Seconds per Core Tick* to 0.

The default reporting behaviour is 1 battery report per day and 1 BLE scan 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: For best results it is not recommended to set the BLE scan report period to less than 60 s. Refer to §**Error! Reference source not found.** for best practices regarding BLE reporting period 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

[14] Battery voltage reporting is no longer supported on Gen2.5 devices. See Table 1-1 for determining generation.

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 receptable to a DL in the short period after sending an UL. Therefore, if the Sensor is configured to send ULs very infrequently or not at all, it could become impossible to send a DL command. As the function button operation (see Sections **Error! Reference source not found.** and **Error! Reference source not found.**) and the magnetic switch operation (see Section **Error! Reference source not found.**) cannot be disabled, it is impossible to completely brick the Sensor with a bad configuration; it is always possible to trigger the Sensor to UL something so it can receive DL commands for a desired configuration change.

However, there are use cases in which using the function button or magnetic switch 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 a large number of devices. In these use cases, strategies to avoid bricking the Sensor are beneficial and included in the FW as follows.

The undesirable combinations that make the Sensor almost or completely irresponsive are:

> *All periodic reports are disabled OR have a minimum period of larger than a week, AND the BLE receiver AND accelerometer are disabled.*

If, after a configuration update request from the NS, the Sensor SW detects that any of the above situations occurs, the SW automatically sets the *core tick* value to 86400 seconds (i.e. one day) and the *ticks per battery* to 1.

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 4-2. To access these registers, a command must be formatted and sent according to the details described in §4.2.2.

Table 5-3: Periodic Transmission 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: 0, 3, 4, …, 86400 • Other values: Invalid and ignored • 0 disables all periodic transmissions	3600 seconds **0x 00 00 0E 10**	*seconds_per_core_tick: <value> (unsigned/sec)*
0x 21	Ticks per Battery	2 B	Access R/W • Ticks between battery reports • Acceptable values: 0, 1, 2, …, 65535 • 0 disables periodic battery reports	24 ticks = 1-day period **0x 00 18**	*ticks_per_battery: <value> (unsigned/no unit)*
0x 24	Ticks per Accelerometer	2 B	Access R/W • Ticks between accelerometer reports • Acceptable values: 0, 1, 2, …, 65535 • 0 disables periodic accelerometer reports	Periodic reporting disabled **0x 00 00**	*ticks_per_accelerometer: <value> (unsigned/no unit)*
0x 25	Ticks per BLE Scan	2 B	Access R/W • Ticks between BLE reports • Acceptable values: 0, 1, 2, …, 65535 • 0 disables periodic BLE reports	1 tick = 1-hour period **0x 00 01**	*ticks_per_ble: <value> (unsigned/no unit)*
0x 28	Ticks per MCU Temperature	2 B	Access R/W • Ticks between temperature reports • Acceptable values: 0, 1, 2, …, 65535 • 0 disables periodic MCU temperature reports	Periodic reporting disabled **0x 00 00**	*ticks_per_mcu_temperature: <value> (unsigned/no unit)*

5.2.2.1 Example DL Payloads

- Disable all periodic events:
  - DL payload: **0x A0 00 00 00 00**
    - Register 0x 20 with bit 7 set to 1 = 0x A0
    - Seconds per Core Tick = 0 = 0x 00 00 00 00

- 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 report BLE scan results every 15 minutes and MCU temperature every hour:
  - DL payload: **0x A0 00 00 01 2C A5 00 01 A8 00 04**
    - Register 0x 20 with bit 7 set to 1 = 0x A0
    - Seconds per core tick = 300 s = 0x 00 00 01 2C
    - Register 0x 25 with bit 7 set to 1 = 0x A5
    - Ticks per BLE Scan = 1 tick = 0x 00 01
    - Register 0x 28 with bit 7 set to 1 = 0x A8
    - Ticks per MCU Temperature = 4 ticks = 0x 00 04

5.3 MCU Data Reporting

5.3.1 Operational Description

The MCU has a built-in thermometer that can be polled for a temperature reading. This temperature represents the *on-board temperature*, not the ambient temperature of the surrounding environment.

The sensor can be configured to report MCU temperature periodically and/or on demand by pressing the function button. By default, the MCU temperature is not reported periodically nor by function button press. The UL report format is always as described in §5.3.2, regardless of report type.

5.3.2 UL Report Frame Format

MCU temperature reports are sent on ***LoRaWAN port 10*** and have the frame format as shown in Figure 4-1. The specific details for the MCU temperature frame format are listed in Table 5-4. For the general description of sensor data report formats and behaviour, see §4.1.1.

Table 5-4: MCU Data Report UL Frame Format Details

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
MCU Temperature	0x 00	0x 67	2 B	Temperature	0.1°C/LSb (signed)	*mcu_temperature (signed/°C)*

5.3.2.1 Example UL Payloads

- **0x 00 67 00 EB**
  - Channel ID = 0x 00, Type ID = 0x 67 → MCU temperature data report
  - 0x 00 EB = 235 × 0.1°C = 23.5°C

- **0x 00 67 00 FE A1**
  - Channel ID = 0x 00, Type ID = 0x67 → MCU temperature data report
  - 0x FE A1 = -351 × 0.1°C = -35.1°C

5.3.3 Configuration Settings

All configuration registers that control MCU reporting behaviour are listed in Table 5-5. In this table, the bit indexing scheme is as shown in Figure 4-2. To access these registers, a command must be formatted and sent according to the details described in §4.2.2.

Table 5-5: MCU Data Reporting Configuration Settings

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: 0, 3, 4, …, 86400 • Other values: Invalid and ignored • 0 disables all periodic transmissions	3600 seconds **0x 00 00 0E 10**	*seconds_per_core_tick: <value> (unsigned/sec)*
0x 28	Ticks per MCU Temperature	2 B	Access: R/W • Ticks between temperature reports • Acceptable values: 0, 1, 2, …, 65535 • 0 disables periodic MCU temperature reports	Periodic reporting disabled **0x 00 00**	*ticks_per_mcu_temperature: <value> (unsigned/no unit)*
0x 2A	Function Button Mode	2 B	Access: R/W • Bit 15: 0/1 = Event Type I/II enabled • Bit 0: 0/1 = Battery report disabled/enabled • Bit 1: 0/1 = Acceleration vector report disabled/enabled • **Bit 2: 0/1 = MCU temperature report disabled/enabled** • Bit 3: 0/1 = BLE report disabled/enabled Unavailable in Beacon Mode • Bits 4-14: Ignored	• Event Type I enabled • BLE report enabled **0x 00 08**	*fb_mode { event_type: <value>, (unsigned/no unit) battery_voltage_report: <value>, (unsigned/no unit) acceleration_vector_report: <value>, (unsigned/no unit) temperature_report: <value>, (unsigned/no unit) ble_report: <value> (unsigned/no unit) }*

5.3.3.1 Periodic Reporting Configuration

The MCU temperature report period can be configured using registers 0x 20 and 0x 28 according to the details described in §5.2.2. That is:

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

Setting the MCU temperature report period to 0 (default) disables periodic reporting of the MCU temperature.

5.3.3.2 Event-Based Reporting Configuration

The MCU temperature can be configured to be reported upon a function button press by setting bit 2 to 1 in the *Function Button Mode* register, 0x 2A. For details about how the function button works and is configured, see §8.

5.3.3.3 Example DL Payloads

- Report MCU temperature every 60 min:
    - DL payload: **0x A0 00 00 0E 10 A8 00 01**
        - Register 0x 20 with bit 7 set to 1 = 0x A0
        - 3600 s/core tick = 0x 00 00 0E 10
        - Register 0x 28 with bit 7 set to 1 = 0x A8
        - Report every 1 tick = 0x 00 01

- Report only MCU temperature upon function button press:
    - DL payload: **0x AA 04**
        - Register 0x 2A with bit 7 set to 1 = 0x AA
        - Value bit 2 set to 1 = 0x 04

5.4 Battery Management

5.4.1 Operational Description

The SPARROW and PELICAN have battery management systems 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.

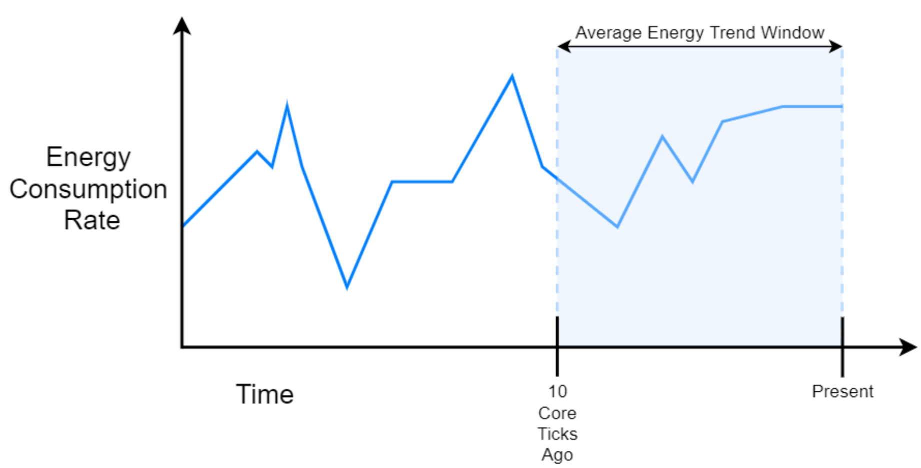


Figure 5-1: Example Visualization of the Default Average Energy Trend Window

The sensor can be configured to send a battery report periodically and/or on demand by pressing the function button. By default, a battery report is sent periodically <u>every 24 hours</u>, and no battery report is sent by function button press.

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 §5.4.2, 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.

NOTE 2: Battery voltage used to be an optional reportable value for Gen1 and Gen2 devices. Voltage measurement is not supported on Gen2.5 sensors. See Table 1-1 for how to determine generation.

5.4.1.1 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).

5.4.1.2 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 (Jauch Marketing Team, 2020). 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 §3.2.1).

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.

5.4.2 UL Report Frame Formats

Battery reports are sent on ***LoRaWAN port 10*** and have the frame format as shown in Figure 4-1. The specific details for the battery report frame formats are listed in Table 5-6. For the general description of sensor data report formats and behaviour, see §4.1.1.

Table 5-6: Battery Report UL Frame Formats

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Remaining Battery Capacity	0x 00	0x D3	1 B	Percentage	1% / LSb (unsigned)	*rem_batt_capacity: <value> (unsigned/%)*
Remaining Battery Lifetime	0x 00	0x BD	2 B	Days	1 day / LSb	*rem_batt_days: <value> (unsigned/days)*
Battery Voltage[15]	0x 00	0x BA	1 B	Analog Voltage	• Bits 0-6: Battery voltage minus 2.5 V (10 mV/LSb, unsigned) • Bit 7: Not used	*battery_status { life: <value>, (unsigned/V) }*

5.4.2.1 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

[15] Battery voltage reporting is not supported on Gen2.5 sensors. See Table 1-1 for how to determine generation.

5.4.3 Configuration Settings

All configuration registers that control battery management behaviour are listed in Table 5-7. In this table, the bit indexing scheme is as shown in Figure 4-2. To access these registers, a command must be formatted and sent according to the details described in §4.2.2.

Table 5-7: Battery Management Configuration Registers

Address	Name	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 20	Seconds per Core Tick	4 B	Access: R/W • Tick value for periodic events [s] • Acceptable values: 0, 3, 4, …, 86400 • Other values: Invalid and ignored • 0 disables all periodic transmissions	3600 seconds **0x 00 00 0E 10**	*seconds_per_core_tick: <value>* *(unsigned/sec)*
0x 21	Ticks per Battery	2 B	Access: R/W • Ticks between battery reports • Acceptable values: 0, 1, 2, …, 65535 • 0 disables periodic battery reports	24 ticks = 1-day period **0x 00 18**	*ticks_per_battery: <value>* *(unsigned/no unit)*
0x 2A	Function Button Mode	2 B	Access: R/W • Bit 15: 0/1 = Event Type I/II enabled • **Bit 0:** **0/1 = Battery report disabled/enabled** • Bit 1: 0/1 = Acceleration vector report disabled/enabled • Bit 2: 0/1 = MCU temperature report disabled/enabled • Bit 3: 0/1 = BLE report disabled/enabled Unavailable in Beacon Mode • Bits 4-14: Ignored	• Event Type I enabled • BLE report enabled **0x 00 08**	*fb_mode {* *event_type: <value>, (unsigned/no unit)* *battery_voltage_report: <value>, (unsigned/no unit)* *acceleration_vector_report: <value>, (unsigned/no unit)* *temperature_report: <value>, (unsigned/no unit)* *ble_report: <value> (unsigned/no unit)* *}*

Address	Name	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 4A	Battery Report Options	1 B	Access: R/W • Bit 0: Ignored (Deprecated; was used for voltage reporting, which is no longer supported in Gen2.5 devices) • Bit 1: 0/1 = Remaining battery capacity [%] not reported/reported • Bit 2: Remaining battery lifetime [days] not reported/reported • Bits 0-2 all set to 0: Invalid and ignored • Bits 3-7: Ignored	Remaining battery capacity [%] and remaining battery lifetime [days] reported **0x 06**	*battery_tx {* *report_voltage_enabled: <value>, (unsigned/no unit)* *report_capacity_enabled: <value> (unsigned/no unit)* *report_lifetime_enabled: <value>, (unsigned/no unit)* *}*
0x 4B	Average Energy Trend Window	1 B	Access: R/W • Bits 0-7: 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**	*avg_energy_trend_window: <value> (unsigned/no unit)*

5.4.3.1 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:

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

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

5.4.3.2 Event-Based Reporting Configuration

The battery can be configured to be reported upon a function button press by setting bit 0 to 1 in the *Function Button Mode* register, 0x 2A. For details about how the function button works and is configured, see §8.

5.4.3.3 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.

5.4.3.4 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.

5.4.3.5 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

- Report battery data and MCU temperature upon function button press:
    - DL payload: **0x AA 05**
        - Register 0x 2A with bit 7 set to 1 = 0x AA
        - Value bit 0 and bit 2 set to 1 = 0x 05

- 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

5.5 General Command-and-Control Operations

5.5.1 List of Operations and Register Values

The general command and control operations supported by the SPARROW and PELICAN are:

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

To perform a command-and-control operation, the appropriate register must be accessed. Table 5-8 lists the details of the command-and-control registers. In this table, the bit indexing scheme is as shown in Figure 4-2. To access these registers, a command must be formatted and sent according to the details described in the following subsections and in §4.2.2.

Table 5-8: Command & Control Register Details

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

Address	Access	Name	Size	Description and Options	JSON Variable (Type/Unit)
0x 71	RO	FW Metadata	7 B	• Bits 48-55: App version major • Bits 40-47: App version minor • Bits 32-39: App version revision • Bits 24-31: LoRaMAC version major • Bits 16-23: LoRaMAC version minor • Bits 8-15: LoRaMAC version revision • Bits 0-7: LoRaMAC region number	*metadata {* *app_ver_major: <value>, (unsigned/no unit)* *app_ver_minor: <value>, (unsigned/no unit)* *app_ver_revision: <value>, (unsigned/no unit)* *loramac_ver_major: <value>, (unsigned/no unit)* *loramac_ver_minor: <value>, (unsigned/no unit)* *loramac_ver_revision: <value>, (unsigned/no unit)* *loramac_region: <value> (unsigned/no unit)* *}*
0x 72	X	Reset Configuration to Factory Defaults	1 B	• 0x 0A: Reset App Configuration • 0x B0: Reset LoRaMAC Configuration • 0x BA: Reset both App and LoRaMAC Configurations • Any other value: Invalid and ignored	*config_factory_reset {* *app_config: <value>, (unsigned/no unit)* *loramac_config: <value> (unsigned/no unit)* *}*

5.5.2 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 4-3. 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 5-8. 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 to 0x 5C) to flash.
- **0x F0 40 00**: Save current configuration settings of all FW LoRaMAC Option registers (0x 10 to 0x 13) 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 §5.5.3. When this option is not selected, the sensor will send a 4B CRC in a UL payload (as described in §4.1.2) in response to receiving the flash write command.

5.5.3 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 §5.5.2 above. In the former case, the explicit payload is **0x F0 00 01**.

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

NOTE: Do not send the reset command as a confirmed DL. The reset command causes the sensor to restart before it can send the acknowledgement UL in response. The sensor will rejoin the network but then get the command sent again from the NS, causing a loop of continual rebooting[16].

5.5.4 Read FW Metadata

The *FW Metadata* register, 0x 71, can be accessed to read the *application version number*, *LoRaMAC version number*, and *LoRaMAC region number*.

[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.

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

After receiving this command, the sensor will respond with a UL message containing the following:

- The fist byte is the register address: 0x 71
- Bits 32 to 55 of the value contain the application revision numbers which define the FW version. The FW version is reported in the format as shown in Figure 5-2, which is shown using the example FW v1.0.15 (value 0x 01 00 0F).

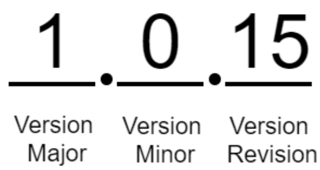


Figure 5-2: Example FW Version Format

- Bits 8 to 31 of the value contain the LoRaMAC 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 LoRaMAC layer of the FW developed by TEKTELIC.
- The last byte contains the LoRaMAC region number. Current LoRaMAC regions and corresponding region numbers for the sensor are listed in Table 5-9.

Table 5-9: LoRaMAC Regions and Region Numbers

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

5.5.5 Factory Reset

The *Reset Configuration to Factory Defaults* register, 0x 72, is used to reset all the configuration register values (0x 10 to 0x 5C) back to the default settings.

The DL payload structure is as shown in Figure 4-3. 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 5-8. Specifically, the payloads for the different factory reset options are:

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

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

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

NOTE: Do not send the factory reset command as a confirmed DL. The command causes the sensor to restart before it can send the acknowledgement UL in response. The sensor will rejoin the network but then get the command sent again from the NS, causing a loop of continual rebooting[17].

[17] 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 BLE Operation

BLE operation is the main function of the SPARROW and PELICAN. Each sensor can operate in 1 of 2 BLE *modes*:

- **Tracker Mode (default)**: The sensor conducts BLE Rx scanning to discover nearby BLE peripherals, determine their signal strengths, and relay this information via LoRaWAN UL to the NS. The primary use case is for indoor positioning/asset tracking.
- **Beacon Mode**: The sensor broadcasts BLE Tx advertisements so it is discoverable to nearby BLE scanning devices. 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 5.0 and uses only the 3 default advertising channels: 37, 38, and 39 (Bluetooth SIG, 2016).

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. All information in this section is applicable to both SPARROW and PELICAN.

6.1 Tracker Mode (BLE Rx)

6.1.1 Operational Description

The default mode of the sensor is tracker mode.

When in tracker mode, the BLE operates in Rx only; the tracker only scans and does not advertise, meaning it is not discoverable by other BLE-capable devices.

During each 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[18] (LoRa Alliance, Feb 2017).

The tracker can be configured to conduct a BLE scan and report periodically. By default, a BLE scan and report is conducted every 60 min.

The tracker can also be configured to conduct additional BLE scans and reports upon the following event-based triggers:

- Function button press: Enabled by default.
- Motion detected and motion cleared through the *Accelerometer Assist*[19] feature: Enabled by default.

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

6.1.1.1 Scanning Scheme

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

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

[18] If a new BLE scan occurs before the results of the previous scan have been sent, the old scan results will be discarded.

[19] See §7.3.2 for a complete description of the Accelerometer Assist feature.

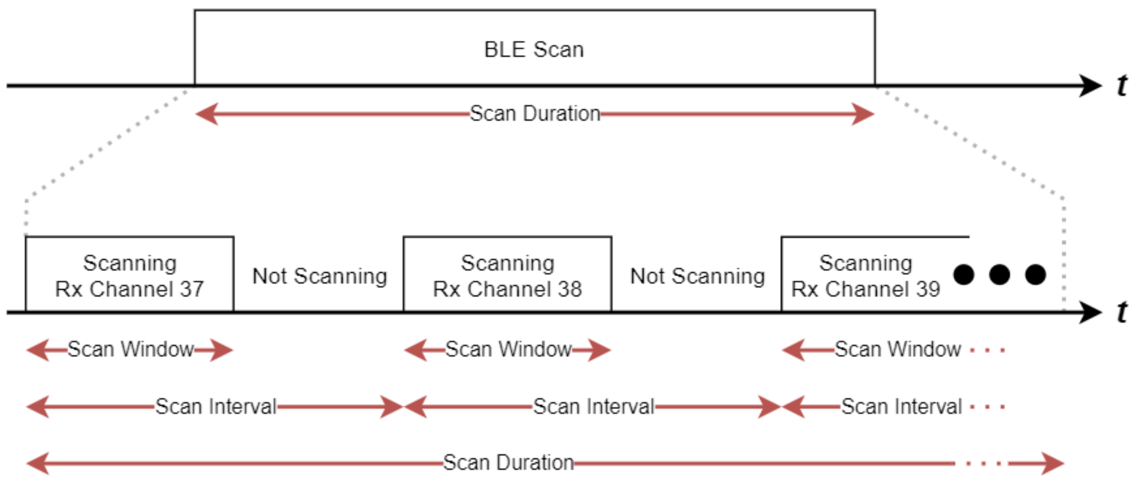


Figure 6-1: The BLE Scan Scheme

Also illustrated in Figure 6-1, 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.

NOTE: The BLE and LoRa radio activity are mutually exclusive; they do not overlap. If any LoRaWAN reporting becomes due at the same time as a BLE scan, the reporting will be done after the BLE scan is complete.

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

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

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

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

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

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

6.1.1.3 Filtering Discovered BLE Devices

The tracker supports inclusion filtering of discovered devices based on BLE Device MAC address, 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:

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

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 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.

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

The range is inclusive, meaning that a BD_{ADDR} equivalent to the start or end bounds is considered in-range. Each range is defined in the following 9-byte format:

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

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

1. A range set to all 0s is an *inactive range*. Otherwise, an *active range*. All ranges are inactive by default.

2. All 4 ranges inactive means **basic reporting** is enabled. Following each scan, any and all discovered devices (up to a maximum *N*) are reported. Otherwise, **filtered reporting** is enabled. Basic reporting is the default behaviour.

3. Following any BLE scan, there will be at least 1 report corresponding to each active range. Each report is sent in a separate UL. Even if no devices from a certain range are discovered, an empty list is always sent for that range. See §6.1.2 for more details on reporting.

4. If a range is defined with $LAP_{start} > LAP_{end}$, the range is active but empty. I.e., an empty list is always reported for that range.

5. If an active range is defined with $LAP_{start} = LAP_{end}$, the range has only one BD_{ADDR} in it. This is *single device filtering*.

6. Ranges are allowed to overlap. A BD_{ADDR} that falls into more than one active range will be reported with the message corresponding to the first range it falls into numerically.

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

6.1.2 UL Report Frame Formats

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

NOTE 1: 0, 1, or more devices can be reported in a single message, depending on the number of devices available to report and payload size limitation as determined by LoRaWAN regional parameters (LoRa Alliance, Feb 2017). 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 (LoRa Alliance, Feb 2017). If a new BLE scan occurs before the results of the previous scan have been sent, the old scan results will be discarded.

6.1.2.1 Basic Reporting

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

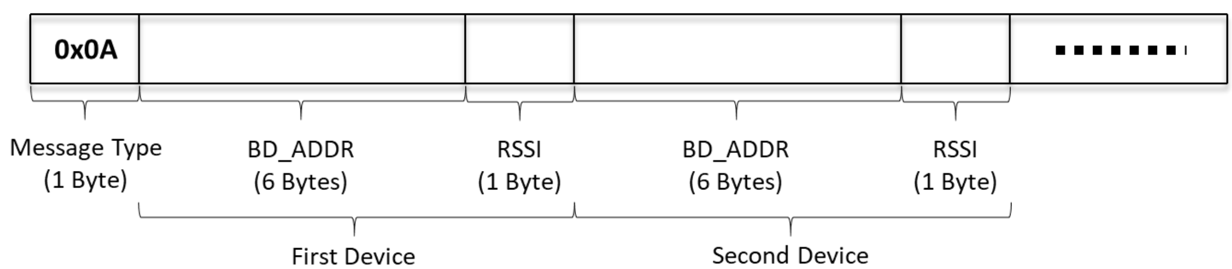


Figure 6-2: The BLE Report UL Payload Format for Basic Reporting

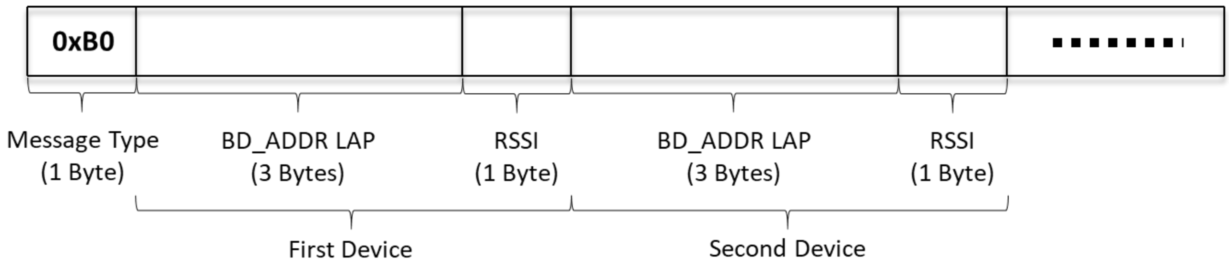
Each payload consists of a 1-byte header (0x 0A) followed by the data from each discovered device. If no devices were discovered during a scan, an empty list (i.e., only the header) is sent.

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

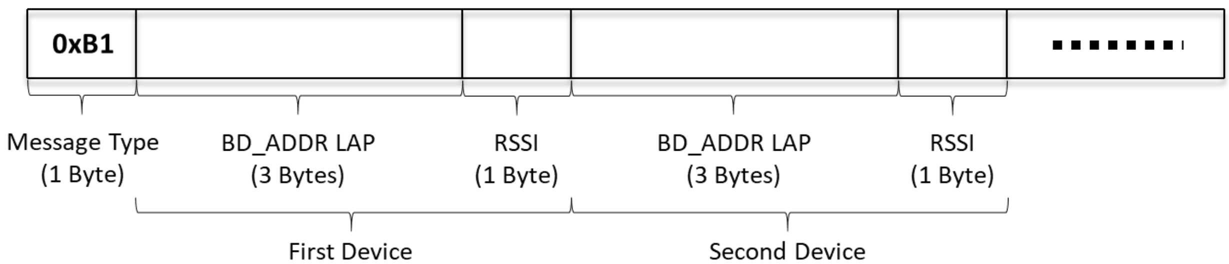
The BD_{ADDR} and RSSI pairs for any other discovered devices are concatenated into the payload. The order of the listed devices depends on whether averaging mode is enabled or disabled (see §6.1.1.2.

6.1.2.2 Filtered Reporting

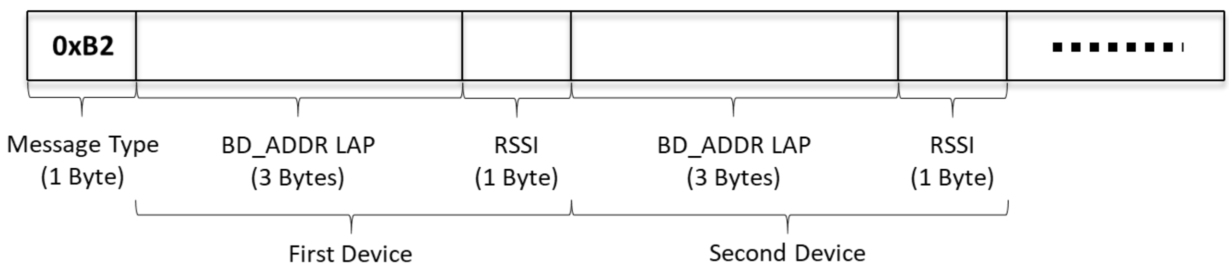
Filtered reporting occurs when one or more filter range is active. In this case, following each scan, only discovered devices (up to a maximum *N*) from specified ranges of favorable BD_{ADDR}s are included in the report. The UL payload formats are shown in Figure 6-3.



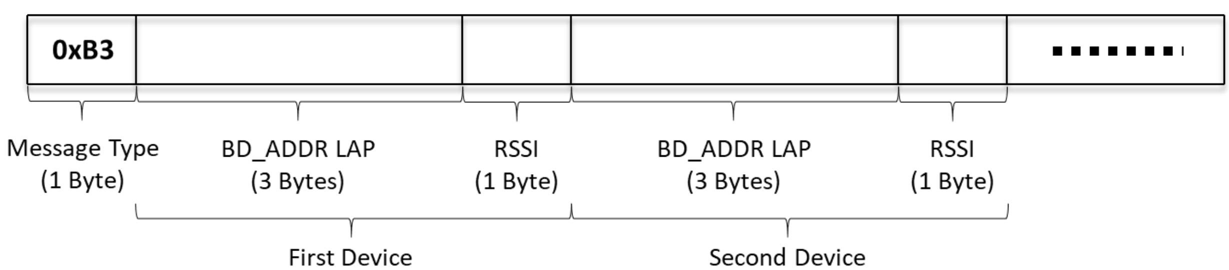
(a) Filter Range 0



(b) Filter Range 1



(c) Filter Range 2



(d) Filter Range 3

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

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

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

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

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

6.1.2.3 Example UL Payloads

- **0x 0A 64 7F DA 00 00 01 C9**
  - Header = 0x 0A → basic BLE data report
  - 0x 64 7F DA 00 00 01 = BD_{ADDR} = 64:7F:DA:00:00:01
  - 0x C9 = RSSI = -55 × 1 dBm = -55 dBm

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

6.1.3 Configuration Settings

Table 6-1 shows the list of configuration registers which affect BLE Rx behaviour. In this table, the bit indexing scheme is as shown in Figure 4-2. To access these registers, a command must be formatted and sent according to the details described in §4.2.2.

Table 6-1: Tracker Mode 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 [s] • Acceptable values: 0, 3, 4, …, 86400 • Other values: Invalid and ignored 0 disables all periodic transmissions	3600 seconds **0x 00 00 0E 10**	*seconds_per_core_tick: <value> (unsigned/sec)*

Address	Value	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 25	Ticks per BLE Scan	2 B	Access R/W • Ticks between BLE reports • Acceptable values: 0, 1, 2, …, 65535 • 0 disables periodic BLE reports	1 tick = 1-hour period **0x 00 01**	*ticks_per_ble: <value>* *(unsigned/no unit)*
0x 2A	Function Button Mode	2 B	Access: R/W • Bit 15: 0/1 = Event Type I/II enabled • Bit 0: 0/1 = Battery report disabled/enabled • Bit 1: 0/1 = Acceleration vector report disabled/enabled • Bit 2: 0/1 = MCU temperature report disabled/enabled • **Bit 3:** **0/1 = BLE report disabled/enabled** **Unavailable in Beacon Mode** • Bits 4-14: Ignored	• Event Type I enabled • BLE report enabled **0x 00 08**	*fb_mode {* *event_type: <value>,* *(unsigned/no unit)* *battery_voltage_report: <value>,* *(unsigned/no unit)* *acceleration_vector_report: <value>,* *(unsigned/no unit)* *temperature_report: <value>,* *(unsigned/no unit)* *ble_report: <value>* *(unsigned/no unit)* *}*
0x 46	Acceleration Event Value to Tx	1 B	Access: R/W • Bit 0: 0/1 = Acceleration alarm UL report disabled/enabled • **Bit 1:** **0/1 = BLE scan report disabled/enabled** • Bits 2-7: Ignored	• Acceleration alarm report UL enabled • BLE scan report enabled **0x 03**	*acceleration_event_tx {* *acceleration_alarm: <value>,* *(unsigned/no unit)* *ble: <value>* *(unsigned/no unit)* *}*
0x 50	BLE Rx Mode	1 B	Access: R/W • Bits 0-6: ***N*** Number of reported devices (1–127) 0: Disables BLE • Bit 7: 0/1 = Averaging mode off/on	• Up to 8 reported devices • Averaging mode on **0x 88**	*ble_mode: {* *num_reported_devices : <value>,* *(unsigned/no unit)* *averaging_mode: <value>* *(unsigned/no unit)* *}*

Address	Value	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 51	BLE Scan Duration	2 B	Access: R/W • Bits 0-7: Scan duration for periodic reports (1 sec/LSb) Acceptable values: 1, 2, …, 255 0: Invalid and ignored • Bits 8-15: Scan duration for event-based reports (1 sec/LSb) Acceptable values: 1, 2, …, 255 0: Invalid and ignored	• 3 seconds for periodic scans • 1 second for event-based scans **0x 01 03**	*ble_scan_duration: {* *periodic: <value>,* *(unsigned/sec)* *event_based: <value>* *(unsigned/sec)* *}*
0x 52	BLE Scan Interval	2 B	Access: R/W • Scan interval (1 ms/LSb) • Acceptable values: "Scan Window", …, 10000 • Other values: Invalid and ignored	30 ms **0x 00 1E**	*ble_scan_interval: <value>* *(unsigned/sec)*
0x 53	BLE Scan Window	2 B	Access: R/W • Scan window (1 ms/LSb) • Acceptable values: 3, …, "Scan Interval" • Other values: Invalid and ignored	30 ms **0x 00 1E**	*ble_scan_window: <value>* *(unsigned/sec)*
0x 54	Filter Range 0	9 B	Access: R/W • Range 0 for filtered BD_{ADDR}s • B_0:B_1:B_2:B_3:B_4:B_5 to B_0:B_1:B_2:B_6:B_7:B_8 ○ OUI = B_0:B_1:B_2 ○ LAP_{start} = B_3:B_4:B_5 ○ LAP_{end} = B_6:B_7:B_8	Range inactive **0x 00 00 00 00 00 00 00 00 00**	*filter_range_0: {* *oui: <value>,* *(unsigned/no unit)* *lap_start: <value>,* *(unsigned/no unit)* *lap_end: <value>* *(unsigned/no unit)* *}*
0x 55	Filter Range 1	9 B	Access: R/W • Range 1 for filtered BD_{ADDR}s • B_0:B_1:B_2:B_3:B_4:B_5 to B_0:B_1:B_2:B_6:B_7:B_8 ○ OUI = B_0:B_1:B_2 ○ LAP_{start} = B_3:B_4:B_5 ○ LAP_{end} = B_6:B_7:B_8	Range inactive **0x 00 00 00 00 00 00 00 00 00**	*filter_range_1: {* *oui: <value>,* *(unsigned/no unit)* *lap_start: <value>,* *(unsigned/no unit)* *lap_end: <value>* *(unsigned/no unit)* *}*

Address	Value	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 56	Filter Range 2	9 B	Access: R/W • Range 2 for filtered BD_{ADDR}s • B_0:B_1:B_2:B_3:B_4:B_5 to B_0:B_1:B_2:B_6:B_7:B_8 ○ OUI = B_0:B_1:B_2 ○ LAP_{start} = B_3:B_4:B_5 ○ LAP_{end} = B_6:B_7:B_8	Range inactive **0x 00 00 00 00 00 00 00 00 00**	*filter_range_2: {* *oui: <value>,* *(unsigned/no unit)* *lap_start: <value>,* *(unsigned/no unit)* *lap_end: <value>* *(unsigned/no unit)* *}*
0x 57	Filter Range 3	9 B	Access: R/W • Range 3 for filtered BD_{ADDR}s • B_0:B_1:B_2:B_3:B_4:B_5 to B_0:B_1:B_2:B_6:B_7:B_8 ○ OUI = B_0:B_1:B_2 ○ LAP_{start} = B_3:B_4:B_5 ○ LAP_{end} = B_6:B_7:B_8	Range inactive **0x 00 00 00 00 00 00 00 00 00**	*filter_range_3: {* *oui: <value>,* *(unsigned/no unit)* *lap_start: <value>,* *(unsigned/no unit)* *lap_end: <value>* *(unsigned/no unit)* *}*

6.1.3.1 Periodic Scanning and Reporting Configuration

The BLE scan period can be configured using registers 0x 20 and 0x 25 according to the equation described in §5.2.2. That is:

$$\textit{BLE Scan Period} = \textit{Seconds per Core Tick} \times \textit{Ticks per BLE Scan}$$

The BLE scan period is equal in value to the BLE report period but scanning and reporting necessarily happen in sequence. As illustrated in Figure 6-4, the BLE scan period specifically defines the period between the starts of consecutive scans and the scan results are reported after each scan concludes. The results are always sent in a LoRaWAN UL within 1 s of to conclusion of the scan, except in some cases when regional duty cycle limitations are in effect[21].

[21] See notes on page 56.

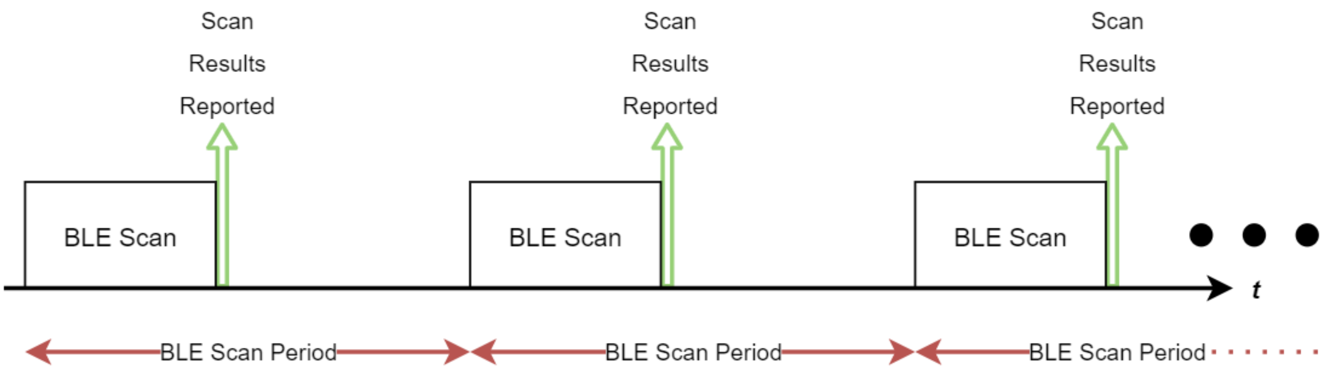


Figure 6-4: Periodic BLE Scanning

Setting the BLE scan period to 0 disables periodic BLE scanning and reporting.

6.1.3.2 Event-Based Scanning and Reporting Configuration

The tracker supports additional, non-periodic BLE scans and reports upon the following event-based triggers:

- Function button press:
  - Setting bit 3 to 1 in the *Function Button Mode* register, 0x 2A, causes a single BLE scan and report to be conducted following a button press detection.
  - Enabled by default.
  - For details about how the function button works and is configured, see §8.
- *Accelerometer Assist*[22] feature:
  - Setting bit 1 to 1 in the *Acceleration Event Value to Tx* register, 0x 46, causes a single BLE scan and report to be conducted when the accelerometer detects the beginning of motion, and another single scan when the accelerometer detects that the motion has cleared.
  - Enabled by default.
  - See §7.3.2 for details about Accelerometer Assist.

NOTE 1: Period and event-based scans have scan durations which are independently configurable. See §6.1.3.3 for details.

NOTE 2: The accelerometer must be enabled in order for Accelerometer Assist to cause event-based BLE scans and reports. See §0 for details.

[22] See §7.3.2 for a complete description of the Accelerometer Assist feature.

6.1.3.3 Operational Configuration

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

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

The scan parameters, namely the *BLE scan durations*, *BLE scan interval*, and *BLE scan window*, are all fined by registers 0x 51, 0x 52, and 0x53, respectively. The periodic scan duration can be configured independently of the event-based scan duration, but the scan interval and scan window apply to both types of scans.

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

6.1.3.4 Guidelines for BLE Scanning and Reporting Configuration

For periodic BLE scanning, although the scan period, scan duration, and number of devices to report can be freely configured to different values, some combinations can result in the tracker not responding as desired. The general rule of thumb is that the scan duration plus the time to report the discovered devices should be smaller than the scan period. The report time is a function of the UL DR and number of devices to report. For example, while a larger DR takes fewer packets to report a number of 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].

Table 6-2 shows the maximum number of BLE devices that can be accommodated in a single packet, as a function of the LoRaMAC region and DR. In the table entries, the first number is for the case of basic reporting, where each device is reported using 7 bytes. The second number is for the case of filtered reporting where 4 bytes is needed per device. For example, from Table 6-2, it respectively takes (at least) 10 and 5 packets to report 10 discovered beacons using DR0 of US915. But the same 10 devices can be reported in 1 packet using DR3 of EU868.

Table 6-2: Maximum Number of Reported BLE Devices per LoRaWAN Packet in Different Regions

Region	DR0	DR1	DR2	DR3	DR4	DR5	DR6
EU868	7/12	7/12	7/12	16/28	34/60	34/60	34/60

Region	DR0	DR1	DR2	DR3	DR4	DR5	DR6
US915	1/2	7/13	17/31	34/60	34/60	N/A	N/A
AS923	7/12	7/12	7/12	16/28	34/60	34/60	34/60
AU915	7/12	7/12	7/12	16/28	34/60	34/60	34/60
IN865	7/12	7/12	7/12	16/28	34/60	34/60	N/A
KR920	7/12	7/12	7/12	16/28	34/60	34/60	N/A
RU864	7/12	7/12	7/12	16/28	34/60	34/60	34/60

Whenever the DR is not certain (e.g., due to enabled ADR, which can change the DR used by the Tracker), it is recommended enough margin for the report time be considered between the scan duration and scan period.

6.1.3.5 *Example DL Payloads*

- Schedule a BLE scan and report every 15 min:
  - DL payload: **0x A0 00 00 00 3C A5 00 0F**
    - Register 0x 20 with bit 7 set to 1 = 0x A0
    - 60 s/core tick = 0x 00 00 00 3C
    - Register 0x 25 with bit 7 set to 1 = 0x A1
    - Scan and report every 15 ticks = 0x 00 0F

- Configure the Tracker to report the nearest (strongest) beacon only:
  - DL payload: **0x D0 81**
    - Register 0x 50 with bit 7 set to 1 = 0x D0
    - Number of reported devices = 1, Averaging mode enabled
      - Value bits 0 and 7 set to 1 = 0x 81

- Decrease the scan duty cycle to 50% from default while keeping scan durations the same to save battery life:
  - DL payload: **0x D3 00 0F**
    - Register 0x 53 with bit 7 set to 1 = 0x D3
    - Scan window 15 ms = 0x 00 0F

- Set filters to only report devices with MAC addresses ABCDEF000001 and ABCDEF500000 to ABCDEF999999:
  - DL payload: **0x D4 AB CD EF 00 00 01 00 00 01 D5 AB CD EF 50 00 00 99 99 99**
    - Register 0x 54 with bit 7 set to 1 = 0x D4
    - Filter range 0 = ABCDEF000001 to ABCDEF000001 = 0x AB CD EF 00 00 01 00 00 01
    - Register 0x 55 with bit 7 set to 1 = 0x D5

        - Filter range 1 = ABCDEF500000 to ABCDEF999999 = 0x AB CD EF 50 00 00 99 99 99

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

6.2 Beacon Mode (BLE Tx)

6.2.1 Operational Description

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

When in beacon mode, the BLE operates in Tx only. It sends out periodic BLE *advertisements* which are small packets of data. These packets are discoverable by other SPARROWs and PELICANs 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 are accessible in either beacon or tracker mode.

When switching to beacon mode, some of the default configuration settings are changed such that the behaviour reflects the standard beacon use-case[23]. Namely, the accelerometer is disabled, the function button press triggers a battery report, and a periodic battery report is sent once every 24 hours.

The following subsections detail the advertising scheme and packet formats.

6.2.1.1 Advertising Scheme

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

The *advertising interval* is the time between the beginnings of consecutive advertisement transmissions as shown in Figure 6-5. It is user-configurable in units of [ms].

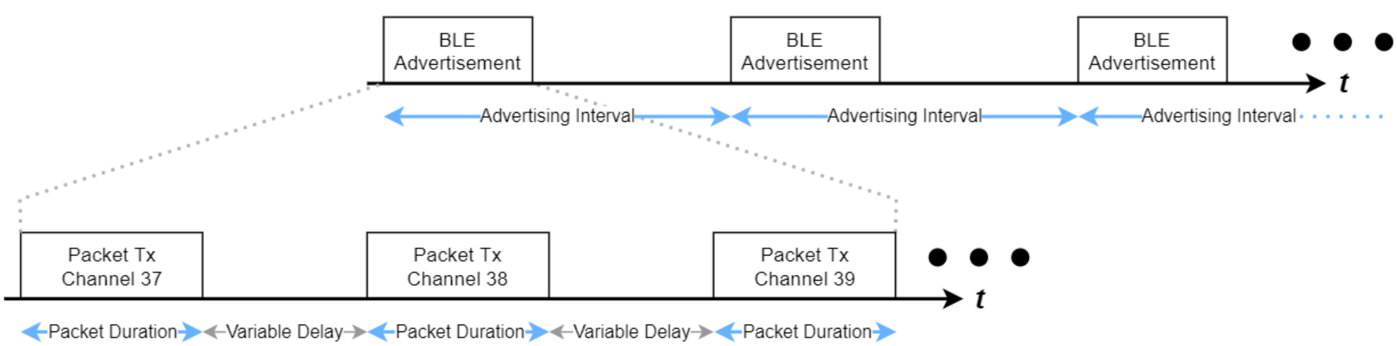


Figure 6-5: The BLE Advertisement Scheme

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

Figure 6-5 also shows that each single BLE advertisement comprises 3 individual packet transmissions, sent one after another on BLE channels 37, 38, and 39 (Bluetooth SIG, 2016). This is to maximize the chances of a BLE device scanning on a single channel receiving 1 packet per advertising interval.

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

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

In addition to the advertising interval, the advertisement *Tx power* level is also 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 is occurring.

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

6.2.1.2 Advertisement Packet Formats

The BLE advertising packet formatting supports 3 major BLE standards: iBeacon, Eddystone UID, and Eddystone TLM. By default, only iBeacon is enabled. Figure 6-6 shows the frame breakdown of each of these packet formats.

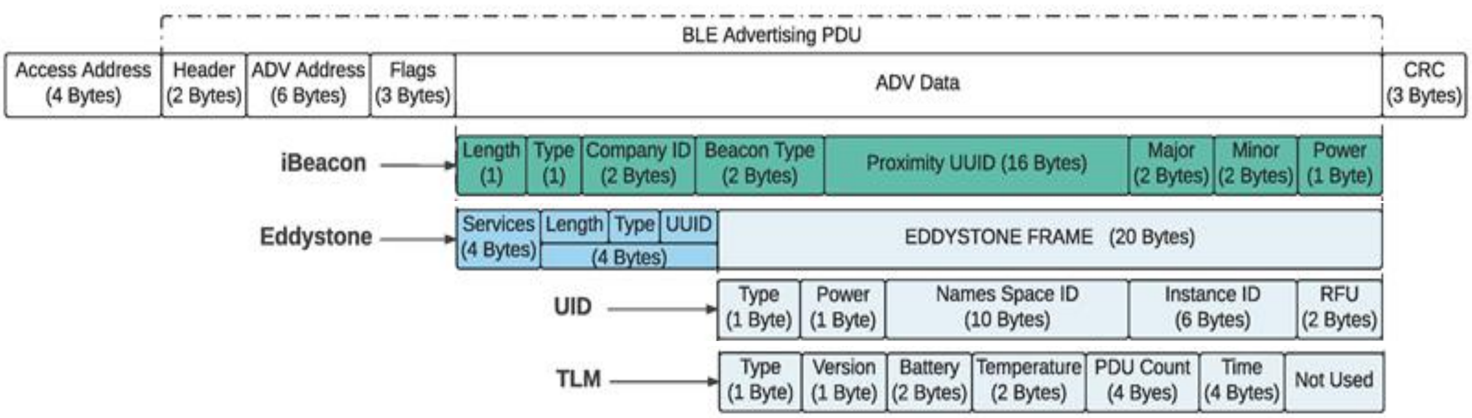


Figure 6-6: Supported Standard BLE Beacon Advertisement Packet Formats

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[24]. 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 <Advertisement Counter>:** This is 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 <Advertisement Counter>:** This is 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 5.0 Core Specification (Bluetooth SIG, 2016).

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.

[24] Gen 2.5 devices always report remaining battery lifetime. Gen2 devices report the battery voltage. This is the same number that gets reported OTA in a LoRaWAN battery report UL, except in this case it is 1 mV/LSB. For example, if the battery voltage was measured to be 3.590 V, then <Battery> would be 0x 0E 06. See Table 1-1 for how to determine generation.

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.

6.2.2 Configuration Settings

Table 6-3 shows the list of configuration registers which affect BLE Tx behaviour. In this table, the bit indexing scheme is as shown in Figure 4-2. To access these registers, a command must be formatted and sent according to the details described in §4.2.2.

Table 6-3: BLE Advertising Configuration

Address	Value	Size	Description and Options	Default Value[25]	JSON Variable (Type/Unit)
0x 58	BLE Advertising Enable / Disable	1 B	Access: R/W • Bits 7-1: Ignored • Bit 0: Advertising enable/disable 0/1 = Advertising off/on	Advertising disabled **0x 00**	*advertising_enabled: <value> (unsigned/no unit)*
0x 59	BLE Advertising Interval	2 B	Access: R/W • Advertising interval (1 ms / LSb) • Acceptable values: 30 ms – 10240 ms • Other values: Invalid and ignored	100 ms **0x 00 64**	*min_advertising_interval: <value> (unsigned/ms)*

[25] The default values in this (and all other tables like it throughout this document) are the sensor default. Since the default sensor mode is tracker mode, all default values represent tracker mode defaults. When the sensor is switched to beacon mode, some default values change automatically. For more information, see §6.3. For a summary of all register default values in both tracker and beacon mode, see Appendix 1 – List of Configuration Registers and Default Values.

Address	Value	Size	Description and Options	Default Value[25]	JSON Variable (Type/Unit)
0x 5B	BLE Tx Advertising Power	1 B	Access: R/W • BLE Tx Power (dBm) [26] ○ 0x 00 = 0 dBm ○ 0x 01 = -0.85 dBm ○ 0x 02 = -1.8 dBm ○ 0x 03 = -3.15 dBm ○ 0x 04 = -4 dBm ○ 0x 05 = -4.95 dBm ○ 0x 06 = -5.9 dBm ○ 0x 07 = -6.9 dBm ○ 0x 08 = -7.8 dBm ○ 0x 09 = -8.85 dBm ○ 0x 0A = -9.9 dBm ○ 0x 0B = -12.05 dBm ○ 0x 0C = -14.1 dBm ○ 0x 0D = -16.5 dBm ○ 0x 0E = -20.85 dBm ○ 0x 0F = -40 dBm • Other values: Invalid and ignored	0 dBm **0x 00**	*tx_advertising_power: <value> (unsigned/no unit)*
0x 5C	BLE Advertisement Packet Format	1 B	Access: R/W • Bit 0: 0/1 = iBeacon advertising disabled/enabled • Bit 1: 0/1 = Eddystone UID advertising disabled/enabled • Bit 2: 0/1 = Eddystone TLM advertising disabled/enabled • Bits 3-7: RFU • All set to 0: invalid and ignored	• iBeacon enabled • Eddystone UID disabled • Eddystone TLM disabled **0x 01**	*advertising_packet_format: { ibeacon: <value>, (unsigned/no unit) eddystone_uid: <value>, (unsigned/no unit) eddystone_tlm: <value> (unsigned/no unit) }*
0x 5F	BLE MAC Address	6 B	Access: RO • The 6-Byte BLE Device MAC address, BD_{ADDR}, of the sensor.	Unique for every sensor	*mac_address: <value>, (unsigned/no unit)*

[26] These are the supported setpoints on Gen2.5 devices. Gen2 devices have different options. See Table 1-1 for how to determine generation.

6.2.2.1 Operational Configuration

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

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

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

6.2.2.2 BLE Device MAC Address

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

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

When the device is switched into Beacon mode (described in Section 6.3), 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 §4.1.2).

6.2.2.3 Example DL Payloads

- Change the Beacon's BLE advertisement power to -3.15 dBm:
  - DL payload: **0x DB 03**
    - Register 0x 5B with bit 7 set to 1 = 0x DB
    - Power setpoint 3 = 0x 03

- Change the advertising interval to 5 s:
  - DL payload: **0x D9 13 88**
    - Register 0x 59 with bit 7 set to 1 = 0x D9
    - Advertising interval = 5000 ms = 0x 13 88

- Read MAC address and change the advertising packet format to Eddystone TLM:
  - DL payload: **0x 5F DC 04**

- Register 0x 5F with bit 7 set to 0 = 0x 5F
- Register 0x 5C with bit 7 set to 1 = 0x DC
- Value bit 2 set to 1 = 0x 04

6.3 Toggling Tracker Mode ↔ Beacon Mode

6.3.1 Toggling Procedure and Commands

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

- ***Tracker mode***: BLE Rx only, see §6.1 for detailed operation descriptions.
- ***Beacon mode***: BLE Tx only, see §6.2 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 §4.2.2. Table 6-4 shows the details and values for register 0x 0A. In this table, the bit indexing scheme is as shown in Figure 4-2.

Table 6-4: 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 • 0x 00 = Tracker Mode • 0x 01 = Beacon Mode	Tracker Mode **0x 00**	*tracker_beacon_mode: <value> (unsigned/no unit)*

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

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

The explicit commands and procedures are as follows.

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

- Sensor behaviour upon rejoin: a BLE scan is conducted and the results of that scan are sent in a UL on ***LoRaWAN port 10***.

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.

6.3.2 Differences Between Modes

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

The default mode is tracker mode, so default sensor configuration settings is equivalent to default tracker mode settings. When switching to beacon mode, a different set of *default beacon mode* configuration values are loaded and used by the sensor after it resets and rejoins the LoRaWAN network (see §6.3.1).

The only default register values that differ between modes are listed in Table 6-5. The default values of all other registers not listed in Table 6-5 are not affected by switching between Tracker and Beacon modes; that is, all other registers do not impact specific Tracker or Beacon mode operation and can be configured independently, regardless of the current mode.

Table 6-5: 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 04 00	0x 00 00
Ticks per BLE Scan	0x 25	0x 00 01	0x 00 00
Function Button Mode	0x 2A	0x 00 08	0x 00 01
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

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 beacon mode is received when already in beacon mode, the sensor will still reset and rejoin with *default beacon configuration*. Consequently, any other configuration and control blocks included in the same payload as a mode switch command block will not be applied.

7 Accelerometer Operation

The SPARROW and PELICAN are each equipped with an accelerometer that can measure the direction and magnitude of acceleration on up to 3 individual axes: ±X, ±Y, and ±Z.

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

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

- **Orientation Detection:** the accelerations on each axis can be reported periodically 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, non-periodic BLE scans and reports can be triggered upon the beginning and end of motion.

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.

7.1 General Sampling Behaviour

7.1.1 Operational Description

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

The acceleration magnitude is measured in units of *acceleration due to gravity*, *g*, where 1 *g* is equivalent to the acceleration experienced by a body at rest on earth's surface: 9.810 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 in order to be accurately measured. Quicker sample rates have a shorter period and can therefore resolve shorter physical acceleration events. However, sampling the transducer at a quicker rate increases the power consumption, impacting the battery life.

The *measurement range* is configurable and defines the full dynamic range of accelerations that can be monitored on any enabled axis. Since the accelerometer output is always an 8-bit signed number, a larger measurement range means less precision (i.e., a larger *g* unit per LSb). Explicitly, the supported measurement ranges of ±2 *g*, ±4 *g*, ±8 *g*, ±16 *g* correspond to typical output precisions of 16 m*g*, 32 m*g*, 64 m*g*, 192 m*g*, respectively[27]. If the physical acceleration magnitude is outside the current measurement range at the time of sampling, it will not be registered.

7.1.2 Configuration Settings

Table 7-5 shows the list of configuration registers which control general accelerometer behaviour. In this table, the bit indexing scheme is as shown in Figure 4-2. To access these registers, a command must be formatted and sent according to the details described in §4.2.2.

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

Table 7-1: General Accelerometer Configuration Registers

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

7.1.2.1 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 listen on Table 7-1

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

7.1.2.2 *Example DL Payloads*

- 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

7.2 Orientation Detection

7.2.1 Operational Description

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

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

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

For a stationary sensor, the total acceleration *magnitude*[28] 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 and/or on demand by pressing the function button. By default, neither periodic nor event-based vector reports are enabled in tracker or beacon mode.

7.2.2 UL Report Frame Formats

Accelerometer vector reports are sent on ***LoRaWAN port 10*** and have the frame format as shown in Figure 4-1. The specific details for the accelerometer vector report frame format are listed in Table 7-2. For the general description of sensor data report formats and behaviour, see §4.1.1.

Table 7-2: Accelerometer Vector Report UL Frame Format

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

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

7.2.2.1 Example UL Payloads

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

7.2.3 Configuration Settings

Table 7-3 shows the list of configuration registers which affect accelerometer vector reporting behaviour. In addition to these registers, the configuration parameters listed in Table 7-1 also affect general accelerometer behaviour. In this table, the bit indexing scheme is as shown in Figure 4-2. To access these registers, a command must be formatted and sent according to the details described in §4.2.2.

Table 7-3: Accelerometer Vector Report Configuration Registers

Address	Name	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 20	Seconds per Core Tick	4 B	Access: R/W • Tick value for periodic events [s] • Acceptable values: 0, 3, 4, …, 86400 • Other values: Invalid and ignored • 0 disables all periodic transmissions	3600 seconds **0x 00 00 0E 10**	*seconds_per_core_tick: <value> (unsigned/sec)*
0x 24	Ticks per Accelerometer	2 B	Access: R/W • Ticks between accelerometer vector reports • Acceptable values: 0, 1, 2, …, 65535 • 0 disables periodic accelerometer vector reports	Periodic reporting disabled **0x 00 00**	*ticks_per_accelerometer: <value> (unsigned/no unit)*

Address	Name	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 2A	Function Button Mode	2 B	Access: R/W • Bit 15: 0/1 = Event Type I/II enabled • Bit 0: 0/1 = Battery report disabled/enabled • **Bit 1:** **0/1 = Acceleration vector report disabled/enabled** • Bit 2: 0/1 = MCU temperature report disabled/enabled • Bit 3: 0/1 = BLE report disabled/enabled Unavailable in Beacon Mode • Bits 4-14: Ignored	• Event Type I enabled • BLE report enabled **0x 00 08**	*fb_mode {* *event_type: <value>, (unsigned/no unit)* *battery_voltage_report: <value>, (unsigned/no unit)* *acceleration_vector_report: <value>, (unsigned/no unit)* *temperature_report: <value>, (unsigned/no unit)* *ble_report: <value> (unsigned/no unit)* *}*

7.2.3.1 Periodic Reporting Configuration

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

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

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

7.2.3.2 Event-Based Reporting Configuration

The accelerometer vector can be configured to be reported upon a function button press by setting bit 1 to 1 in the *Function Button Mode* register, 0x 2A. For details about how the function button works and is configured, see §8.

7.2.3.3 Example DL Payloads

- 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

- Report acceleration vector upon function button press:
    - DL payload: **0x AA 02**
        - Register 0x 2A with bit 7 set to 1 = 0x AA
        - Value bit 1 set to 1 = 0x 02

7.3 Motion Detection Alarms

7.3.1 Operational Description

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

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

To determine when motion is detected, ***acceleration triggers*** are used. An acceleration trigger is registered when a number of acceleration samples 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*) one 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.

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 alarm clear is registered, even if more acceleration triggers are registered.

Alarm reporting is enabled by default but can be disabled without turning the accelerometer off. All alarm reporting is event-based; no periodic reporting behaviour is supported.

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

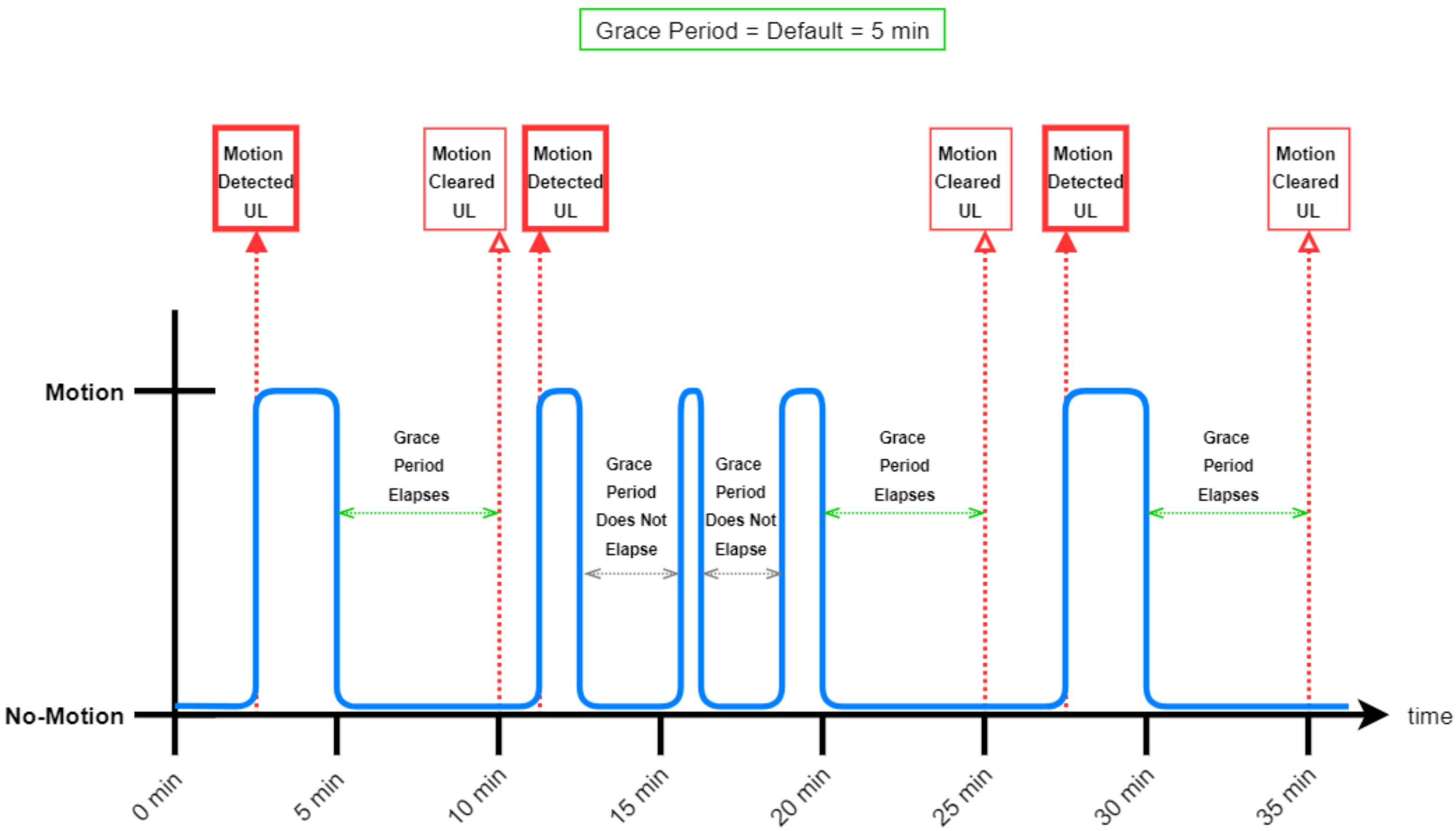


Figure 7-1: Example Sequence of Accelerometer Events and UL Reports

7.3.2 UL Report Frame Formats

Accelerometer alarm reports are sent on ***LoRaWAN port 10*** and have the frame format as shown in Figure 4-1. The specific details for the alarm report frame format are listed in Table 7-4. For the general description of sensor data report formats and behaviour, see §4.1.1.

Table 7-4: Accelerometer Vector Report UL Frame Format

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

7.3.2.1 Example UL Payloads

- **0x 00 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

7.3.3 Configuration Settings

Table 7-5 shows the list of configuration registers which affect accelerometer alarm reporting behaviour. In addition to these registers, the configuration parameters listed in Table 7-1 also affect general accelerometer behaviour. In these tables the bit indexing scheme is as shown in Figure 4-2. To access these registers, a command must be formatted and sent according to the details described in §4.2.2.

Table 7-5: Accelerometer Motion Detection Alarm Configuration Registers

Address	Value	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 42	Acceleration Trigger Threshold Count	2 B	Access: R/W • Number of above-threshold acceleration samples before an acceleration alarm is registered • Acceptable values: ≥ 1 • 0: Invalid and ignored	1 trigger **0x 00 01**	*acceleration_trigger_threshold_count: <value> (unsigned/no unit)*
0x 43	Acceleration Trigger Threshold Period	2 B	Access: R/W • Period in s over which acceleration samples are counted for threshold detection • Acceptable values: ≥ 5 • 0-4: Invalid and ignored	10 seconds **0x 00 0A**	*acceleration_trigger_threshold_period: <value> (unsigned/sec)*
0x 44	Acceleration Trigger Threshold	2 B	Access: R/W • Unsigned, 1 milli-g/LSb	2 *g* **0x 07 D0**	*acceleration_trigger_threshold: <value> (unsigned/g)*
0x 45	Acceleration Event Grace Period	2 B	Access: R/W • Time to pass in s after the last acceleration alarm before the alarm is cleared • Acceptable values: ≥ 15 • 0-14: Invalid and ignored	5 min **0x 01 2C**	*acceleration_event_grace_period: <value> (unsigned/sec)*

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

7.3.3.1 Operational Configuration

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

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

7.3.3.2 Example DL Payloads

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

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

7.4 Accelerometer Assist for BLE Asset Tracking

7.4.1 Operational Description

In addition to motion detection alarm reporting as described in §7.3, *accelerometer events* and *acceleration clears* can trigger nonperiodic BLE scans. That is, when the ***Accelerometer Assist*** function is enabled, event-based BLE scans and reports are triggered when:

- New motion is detected.
- The motion has ended.

In the indoor asset tracking use-case, Accelerometer Assisted BLE scans applied in conjunction with periodic ones help get BLE indoor location updates at these 2 critical times when assets leave locations and settle in new ones.

Accelerometer Assist is triggered under the same configurable conditions as acceleration alarm reporting (namely, the threshold criteria for accelerometer triggers, events, and clears as defined by the *Acceleration Trigger Threshold Count*, *Acceleration Trigger Threshold Period*, *Acceleration Trigger Threshold*, and *Acceleration Event Grace Period* registers).

If Accelerometer Assist is enabled, a single BLE scan and report is triggered by each accelerometer event and with each accelerometer clear. See §7.3 for details on how these are registered. See §6.1 for details about BLE scanning and reporting operation.

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

7.4.2 UL Report Frame Formats

The BLE results from an Accelerometer Assisted BLE scan have the same report format as all other BLE reports. See §6.1.2 for details.

7.4.3 Configuration Settings

Table 7-6 shows the list of configuration registers which affect accelerometer assist behaviour. In addition to these registers, the configuration parameters listed in Table 7-1 also affect general accelerometer behaviour. In these tables the bit indexing scheme is as shown in Figure 4-2. To access these registers, a command must be formatted and sent according to the details described in §4.2.2.

Table 7-6: Accelerometer Assist Configuration Registers

Address	Value	Size	Description and Options	Default Value	JSON Variable (Type/Unit)
0x 42	Acceleration Trigger Threshold Count	2 B	Access: R/W • Number of above-threshold acceleration samples before an acceleration alarm is registered • Acceptable values: ≥ 1 • 0: Invalid and ignored	1 trigger **0x 00 01**	*acceleration_trigger_threshold_count: <value> (unsigned/no unit)*
0x 43	Acceleration Trigger Threshold Period	2 B	Access: R/W • Period in s over which acceleration samples are counted for threshold detection • Acceptable values: ≥ 5 • 0-4: Invalid and ignored	10 seconds **0x 00 0A**	*acceleration_trigger_threshold_period: <value> (unsigned/sec)*
0x 44	Acceleration Trigger Threshold	2 B	Access: R/W • Unsigned, 1 milli-g/LSb	2 *g* **0x 07 D0**	*acceleration_trigger_threshold: <value> (unsigned/g)*
0x 45	Acceleration Event Grace Period	2 B	Access: R/W • Time to pass in s after the last acceleration alarm before the alarm is cleared • Acceptable values: ≥ 15 • 0-14: Invalid and ignored	5 min **0x 01 2C**	*acceleration_event_grace_period: <value> (unsigned/sec)*
0x 46	Acceleration Event Value to Tx	1 B	Access: R/W • Bit 0: 0/1 = Acceleration alarm UL report disabled/enabled • **Bit 1:** **0/1 = Accelerometer Assist BLE scan report disabled/enabled** • Bits 2-7: Ignored	• Acceleration alarm report UL enabled • Accelerometer Assist enabled **0x 03**	*acceleration_event_tx {* *acceleration_alarm: <value>, (unsigned/no unit)* *ble: <value> (unsigned/no unit)* *}*

7.4.3.1 Operational Configuration

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

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

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

7.4.3.2 Example DL Payloads

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

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

8 Function Button Operation

Only the SPARROW is equipped with a function button; the information in this section is not applicable to PELICAN.

The function button is externally accessible and located on the bottom of the enclosure as shown in Figure 3-1. It is actuated by pressing until the haptic click feedback is felt.

The primary purpose of the function button is to elicit a non-periodic UL from the sensor. This also allows it, as a LoRaWAN Class-A end-device, to open receive windows to receive DL commands.

The button actuation pattern as well as the resulting action(s) are configurable. The details are described in the following subsections.

8.1.1 Actuation Pattern

The pattern required to register a function button event is configurable. Two types of actuation event patterns are defined:

- **Event Type I**: Press the button *for at least* m times within n s.
- **Event Type II**: Press and hold the button *for at least* T sec.

Event Type I is registered *as soon as* the button is pressed m times within n sec. Event Type II is registered *as soon as* the button is pressed and held for T sec.

One and only one event type is enabled at any time, and therefore, the function button operation cannot be disabled. The sensor is triggered to send an uplink when the enabled event type actuation pattern is registered.

Event Type I is enabled by default.

8.1.2 Resulting Action

Once a function button press is registered, a resulting action is configurable. All actions involve sending a LoRaWAN UL. The possible actions are:

- Battery report UL sent on ***LoRaWAN port 10***.
- Acceleration vector report UL sent on ***LoRaWAN port 10***.
- MCU temperature report UL sent on ***LoRaWAN port 10***.
- BLE scan triggered, followed by the scan results report UL on ***LoRaWAN port 25***.

In each case, the UL report formats are as described in §4.1.1; i.e., they are identical to other reports of the same type.

Any combination of these options can be selected. When more than 1 action is selected which results in a report UL sent on the same port, all action data will be sent in 1 payload.

None of the options can be enabled, in which case a button press elicits a report UL with an empty frame payload sent on ***LoRaWAN port 10***.

In tracker mode, the default action upon button press is a BLE scan and report. In beacon mode, the default action upon button press is a battery report.

8.1.3 Configuration Settings

Table 8-1 shows the list of configuration registers which control function button behaviour. In this table, the bit indexing scheme is as shown in Figure 4-2. To access these registers, a command must be formatted and sent according to the details described in §4.2.2.

Table 8-1: Function Button Configuration Registers

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x 2A	Function Button Mode	2 B	Access: R/W • Bit 15: 0/1 = Event Type I/II enabled • Bit 0: 0/1 = Battery report disabled/enabled • Bit 1: 0/1 = Acceleration vector report disabled/enabled • Bit 2: 0/1 = MCU temperature report disabled/enabled • Bit 3: 0/1 = BLE report disabled/enabled Unavailable in Beacon Mode • Bits 4-14: Ignored	• Event Type I enabled • BLE report enabled **0x 00 08**	*fb_mode {* *event_type: <value>,* *(unsigned/no unit)* *battery_voltage_report: <value>,* *(unsigned/no unit)* *acceleration_vector_report: <value>,* *(unsigned/no unit)* *temperature_report: <value>,* *(unsigned/no unit)* *ble_report: <value>* *(unsigned/no unit)* *}*

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x 2B	Event Type I Configuration	1 B	Access: R/W • Bits 0-3: Value of m Acceptable values: 1, 2, …, 15 Other values: Invalid and ignored • Bits 4-7: Value of n Acceptable values: 1, 2, …, 15 Other values: Invalid and ignored • $m > 2n$: Invalid and ignored	• m = 1 • n = 1 **0x 11**	*fb_event_type1 {* *m_value: <value>,* *(unsigned/no unit)* *n_value: <value>* *(unsigned/no unit)* *}*
0x 2C	Event Type II Configuration	1 B	Access: R/W • Value of T Acceptable values: 1, 2, …, 15 Other values: Invalid and ignored	T = 1 **0x 01**	*fb_event_type2 {* *t_value: <value>* *(unsigned/no unit)* *}*

8.1.3.1 Operational Configuration

Bit 15 of the *Function Button Mode* register determines which event type is desired. Bits 0-3 determine what the sensor action is and what is transmitted when an event is registered.

Registers 0x 2B and 0x 2C configure Event Types I and II, respectively. Note that trying to set m, n, or T to 0 is invalid and ignored by the SW. Also, for Event Type I, trying to set m or n in a way that $m > 2n$ is invalid and ignored by the SW. This is to avoid a situation where the user is needed to press the button too fast to register a function button event. For example, it is impractical for a human to press the function button 15 times in 1 s.

8.1.3.2 Example DL Payloads

- Enable BLE report and battery report (with event type II):
  - DL payload: **0x AA 80 09**
    - Register 0x 2A with bit 7 set to 1 = 0x AA
    - Value bits 0, 3, and 15 set to 1 = 0x 80 09

- Read current value of *Event Type II Configuration:*
  - DL payload: **0x 2C**
    - Register 0x 2C with bit 7 set to 0 = 0x 2C

Appendix 1 – List of Configuration Registers and Default Values

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
Join Mode	10	80 00	80 00	LoRaMAC
LoRaMAC Options	11	00 0E	00 0E	
LoRaMAC DR and Tx Power	12	04 00	00 00	
LoRaMAC Rx2 Window	13	As per Table 5-2		
Seconds per Core Tick	20	00 00 0E 10	00 00 0E 10	Periodic Reporting
Ticks per Battery	21	00 18	00 18	
Ticks per Accelerometer	24	00 00	00 00	
Ticks per BLE	25	00 01	00 00	
Ticks per MCU Temperature	28	00 00	00 00	
Mode	2A	00 08	00 01	Function Button
Event Type I Configuration	2B	11	11	
Event Type II Configuration	2C	01	01	
Mode	40	87	07	Accelerometer
Sensitivity	41	22	22	
Acceleration Event Threshold Count	42	00 01	00 01	
Acceleration Event Threshold Period	43	00 0A	00 0A	
Acceleration Event Threshold	44	07 D0	07 D0	
Acceleration Event Grace Period	45	01 2C	01 2C	
Acceleration Event Value to Tx	46	03	03	
Battery Report Options	4A	06	06	Battery Management
Average Energy Trend Window	4B	0A	0A	
Mode	50	88	88	BLE Scanning (Tracker Mode)
Scan Duration	51	01 03	01 03	
Scan Interval	52	00 1E	00 1E	
Scan Window	53	00 1E	00 1E	
Filter Range 0	54	00 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00 00	
Filter Range 1	55	00 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00 00	
Filter Range 2	56	00 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00 00	
Filter Range 3	57	00 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00 00	
Advertising Enable / Disable	58	00	01	BLE Advertising (Beacon Mode)
Advertising Interval	59	00 64	00 64	
Tx Advertising Power	5B	00	00	
Advertisement Packet Format	5C	01	01	
BLE MAC Address	5F	Unique for every device		

Appendix 2 – List of Sensor Data Report UL Frame Formats

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Battery Voltage[29]	0x 00	0x BA	1 B	Analog Voltage	• Bits 0-6: Battery voltage minus 2.5 V (10 mV/LSb, unsigned) • Bit 7: Not used	*battery_status {* *life: <value>,* *(unsigned/V)* *}*
Remaining Battery Capacity	0x 00	0x D3	1 B	Percentage	• 1% / LSB (unsigned)	*rem_batt_capacity: <value>* *(unsigned/%)*
Remaining Battery Lifetime	0x 00	0x BD	2 B	Days	• 1 day / LSB	*rem_batt_days: <value>* *(unsigned/days)*
Acceleration Alarm Status	0x 00	0x 00	1 B	Digital Input	• 0x 00 = Alarm inactive (motion no longer detected) • 0x FF = Alarm active (motion detected)	*acceleration_alarm* *(unsigned/no unit)*
Acceleration Vector	0x 00	0x 71	6 B	Acceleration	• 1 milli-g/LSb (signed) • Bits 32-47: X-axis acceleration • Bits 16-31: Y-axis acceleration • Bits 0-15: Z-axis acceleration	*acceleration_vactor {* *xaxis: <value>,* *(signed/g)* *yaxis: <value>,* *(signed/g)* *zaxis: <value>* *(signed/g)* *}*
MCU Temperature	0x 00	0x 67	2 B	Temperature	• 0.1°C/LSb (signed)	*temperature* *(signed/°C)*

[29] Battery voltage reporting is not supported on Gen2.5 sensors. See Table 1-1 for how to determine generation.

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