TEKTELIC Communications Inc.
7657 10th Street NE Calgary, Alberta
Canada, T2E 8X2

ORCA

Industrial GPS Asset Tracker

Technical Reference Manual

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Revision History

<table>
<tr><th>TRM Version</th><th>Date</th><th>Editor</th><th>FW Version</th><th>Comments</th></tr>
<tr><td>0.1</td><td>August 13, 2019</td><td>Reza Nikjah</td><td>0.1.0</td><td>First draft (based off T0005486_v0.2 and updates from Oleg on Aug 6, 2019).
Updates made:
Changed documentation T-Code from T0005486 to T0006279.
Added support for GNSS log request and report
Added FSM Description and BLE Operation sections
Updated Battery Reports to have EoS alarm and battery voltage
Added FSM State, GNSS Geofence Status, Acceleration Alarm Status, Acceleration Vector, and BLE Device Information UIs
Added BLE ticks for DEFAULT, STILLNESS, and MOBILITY states to Periodic Tx Configuration
Updated anti-bricking strategy
Enhanced GNSS Value to Tx to include more options and increased number of geofence areas to 4 zones
Redefined accelerometer definition and configuration to make it like Smart Room Sensors. Differences: Just one acceleration event that is much similar to Room Sensor's Impact Alarm, with the exception that alarm reporting here can be suppressed. Also, periodic reporting here is limited to acceleration vector.
Added a tentative section for BLE configuration
DL configuration register addresses have been shuffled around in many cases to retain a logical order.</td></tr>
<tr><td>0.2</td><td>October 15, 2019</td><td>Conor Karperien</td><td>0.1.0</td><td>Changed formatting to reflect design updates</td></tr>
</table>

TRM Version	Date	Editor	FW Version	Comments
0.3	December 2, 2019	Reza Nikjah	0.2.0	• Removed support to read LoRa commissioning information through registers 0x00 to 0x05 (either for security, or no need to keep the support) • Named the product Industrial GPS Asset Tracker • Limited the product to 2X D-Cell NA/EU version, and removed CN variant that is not supported yet • Added BLE support (essentially the same as in the BLE Asset Tracker) • Added Reed Switch support to reset the Tracker either out of DEEP SLEEP or during normal operation, and also to trigger the Tracker to uplink something • Simplified FSM: ○ No need to search with variable searching frequencies if a fix isn't available. An appropriate power saving mode of the GNSS receiver will take care of fix unavailability situations. • New registers for MOBILITY and STILLNESS states speed thresholds and average speed counts. These thresholds and counts are used to handle transitions between the states. • Removed Acquisition Timeout and Data Logging Control configurability. The GNSS receiver default behavior for acquisition should be just fine. Also, the logging is always enabled. These two registers were replaced by Speed Thresholds and Average Speed Counts registers. • Changed the bit indexing scheme from bytes and bits to only bits, with the rightmost bit indexed 0, for more clarity

TRM Version	Date	Editor	FW Version	Comments
0.4	March 15, 2020	Reza Nikjah	0.3.22	• Added other LoRaWAN RF variants • Specified LEDs operation • Added a table of default values for all config registers • Added an anti-bricking strategy • Cleaned up and updated the state machine • Clarified accelerometer operation • Shuffled BLE config registers, added BLE scan duration for event-based (i.e. reed switch triggered) BLE scans • Set default behavior of reed switch event to report last GNSS logged UTC and position fix • Configurable BLE scan duration for event-based BLE scans
0.5	March 24, 2020	Reza Nikjah	0.3.23	• Added diagrams to the LEDs Behavior section • Added SW variable names to the table of default values • Editorial changes
0.6	April 13, 2020	Reza Nikjah	0.3.27	• Changing the default values for periodic transmissions and BLE scan • Minor corrections (e.g. default value of Reg 0x40 in the Appendix table).
0.7	May 13, 2020	Reza Nikjah	0.3.34	• Updated magnetic wake-up pattern. • Specified an LED pattern for going to Deep Sleep. • Updated BLE operation to match the BLET (added Whitelisting and Repetition modes). • Added JSON variables for UL and DL encoding and decoding. • Minor edits. • Changed definition of Fix Status UL. • Changed Channel ID and Type ID for Geofence Status. • Removed limitation on the number of GNSS log entries to request in a single message.
0.8	May 14, 2020	Reza Nikjah	0.3.35	• Simplified magnetic wake-up/reset pattern. • Simplified Reed Switch operation to trigger ULs. • Specified that there will be the same LED pattern to get out of Deep Sleep as for going into Deep Sleep.

TRM Version	Date	Editor	FW Version	Comments
0.9	May 30, 2020	Reza Nikjah	0.3.37	• Updated battery lifetime estimate. • Changed default values of some of App Config registers. • Updated LED indications for going into and out of DEEP SLEEP, to make it as already implemented. • Changed minimum Core Tick to 3 sec. • Added register 0x29 for FSM State Tick. • Added FSM State report to reed switch configuration. • Removed FSM State Report bit from GNSS Value to Tx. • Modified anti-bricking strategy so not to change Core Tick. • Added a section for Guidelines on BLE Scan Configuration. • Clarified the specification around disabling a transducer.
0.10	June 1, 2020	Reza Nikjah	0.3.38	Added Ground Speed as one of possible values to transmit for GNSS
0.11	April 11, 2022	Carter Mudryk	0.3.52	• Added information about sending motion reports when motion stops (updated accelerometer assist function), including updated FSM. • Changed default value of register 0x44. • Updated List of Acronyms. • Updated BLE Section 1.2 for clarity. • Changed “whitelisting” terminology to “filtered reporting.” • Corrected LED pattern descriptions in Section 1.4. • Updated BLE UL format Section 2.3 for clarity. • Updated response to configuration and control commands description in Section 2.4 for clarity. • Updated Accelerometer Configuration description Section 3.2.5 for clarity. • Added missing subsections in Section 3.2.8. • Minor formatting changes.
0.12	May 27, 2022	Carter Mudryk	0.3.54	Corrected and clarified Geofence Status reporting description in §3.2.4.4.
0.13	May 29, 2022	Carter Mudryk	0.3.54	• Minor grammatical corrections. • Corrected default value of register 0x30 in Table 3-7. • Corrected failed POST LED pattern in Section 1.4.1. • Moved FW versioning notes to Revision History table. • Updated product name terminology to “ORCA.”

TRM Version	Date	Editor	FW Version	Comments
0.14	October 26, 2022	Carter Mudryk	0.3.59	• Corrected and updated finite state machine diagram and description. • Updated warning for configuring GPS reporting periods to < 3 min.

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List of Acronyms

ABP .... Activation By Personalization
ADR..... .... Adaptive Data Rate
BD_ADDR......... Bluetooth Device ADDRess
BLE .... Bluetooth Low Energy
CRC...... .... Cyclic Redundancy Check
DL........ .... DownLink
DR .... Data Rate
EIRP..... .... Effective Isotropic Radiated Power
EoS .... End of Service
EU .... EUrope
FSM..... .... Finite State Machine
FW....... .... FirmWare
GLONASS .... GLObal NAvORCAion Satellite System
GNSS ... . Global NavORCAion Satellite System
GPS .... Global Positioning System
ID .... IDentity / Identifier
ORCA... .... Industrial GPS Asset Tracker
IoT .... Internet of Things
IP .... Ingress Protection
JSON.... .... JavaScript Object Notation
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
OUI .... Organizationally-Unique Identifier
POST.... .... Power-On Self-Test
QZSS .... Quasi-Zenith Satellite System
Reg .... Register
RF .... Radio Frequency
RFU...... .... Reserved for Future Use
RO .... Read Only
R/W..... .... Read/Write
RSSI .... Received Signal Strength Indicator
Rx .... Receive / Receiver
SBAS .... Satellite-Based Augmentation System
SW....... .... SoftWare
TRM..... .... Technical Reference Manual
Tx......... .... Transmit / Transmitter
UL .... UpLink
UTC...... .... Coordinated Universal Time
v........... .... version
ver. .... version

1 Overview

IMPORTANT: Not all features described in this manual may be applicable to devices 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 device has, send a command to query your device as described in Section 3.2.8.

This document contains the technical information about the supported functionality of the TEKTELIC ORCA [*Industrial GPS Asset Tracker*], referred to as the *Tracker* or *ORCA* henceforth. 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 Tracker is a GNSS-capable LoRaWAN IoT sensor run on LTC batteries and packed into a small IP67 casing. The GNSS receiver in the Tracker supports receiving GPS, GLONASS, Galileo, BeiDou, QZSS, and SBAS signals. The Tracker is thus ideal for monitoring and reporting geolocation in industrial environments in different parts of the world.

The Tracker also supports BLE and is capable of scanning and reporting neighboring BLE devices (up to the LoS range of approximately 70 m) to provide location information, which can be particularly helpful in indoor environments with poor to no GNSS coverage.

The Tracker is also equipped with an accelerometer that can generate alarm events based on configurable thresholds. The accelerometer can help detecting the Tracker status change between stillness and mobility to optimize power usage by reporting the GNSS fixes when and how often needed. The accelerometer output vector can also be reported periodically if knowledge of the Tracker orientation is of interest.

Additional sensing functions on the Tracker include on-board temperature, the battery voltage, and the battery EoS alarm.[1] The Tracker can achieve an estimated battery lifetime of at least 5 years.[2]

Table 1-1 presents the currently available Tracker HW variant. The phrase "2x D-Cell" in this model refers to having 2 battery holders to receive up to 2 D-cell LTC batteries. Table 1-2 lists the ORCA variants for the different RF regions identified by the LoRa Alliance [1]—also see [1] for the

[1] The EoS alarm is not supported in SW 0.3.xx.

[2] Based on the room temperature, 2x D-Cell of 19 Ah nominal capacity each, and default configuration for the Tracker.

Tx and Rx bands in each LoRaWAN region. As shown in Table 1-2, the different RF variants use the same HW. In fact, they are distinguished through different, specialized FW.

Table 1-1: ORCA HW Model

Product Code	Description
T0006129	Industrial GPS Asset Tracker Module, 2x D-Cell, NA/EU

Table 1-2: ORCA Region Specific Variants

LoRaWAN RF Variant	Corresponding HW Variant	Order Code
EU868	NA/EU (T0006129)	INDTNEU868
US915	NA/EU (T0006129)	INDTNUS915
AS923	NA/EU (T0006129)	INDTNAS923
AU915	NA/EU (T0006129)	INDTNAU915
IN865	NA/EU (T0006129)	INDTNIN865
KR920	NA/EU (T0006129)	INDTNKR920
RU864	NA/EU (T0006129)	INDTNRU864

Information streams supported by the SW have been shown in Table 1-3 and the default configuration on the Tracker for reporting transducer readings has been shown in Table 1-4.

Table 1-3: ORCA Information Streams

Stream Direction	Data Type	Sent on LoRaWAN Port
UL (Tracker to NS)	Real-time sensor data from the MCU, GNSS receiver, battery gauges, and accelerometer	**10**
	Report GNSS logged (historical) time and position	**15**
	Report discovered BLE devices	**25**
	Response to Configuration and Control Commands	**100**
DL (NS to Tracker)	Request GNSS logged (historical) time and position	**15**
	Configuration and Control Commands	**100**

Table 1-4: ORCA Default Reporting Behavior

Report	Report Type	Periodicity
Battery voltage	Periodic	1 day
UTC and GNSS position fix	Periodic	1 hour
	Event-Based	Every time the accelerometer threshold is breached (when motion begins)
	Event-Based	Every time the accelerometer grace period elapses (when motion stops)
Discovered BLE devices (up to 8) with RSSIs after scanning for 3 seconds	Periodic	6 hours
FSM State	Event-Based	Every time the magnet is used to force UL

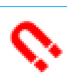
In Sections 2 and 3, the UL and DL payload formats are explained, respectively. Refer to the *Industrial GPS Asset Tracker UL/DL Decoding/Encoding Tool* [2] for a thorough spreadsheet tool to decode any UL frame payload, as well as encode any DL frame payload by varying parameter values, toggling read/write actions, and enabling/disabling different fields as desired.

1.1 Finite State Machine Description

Figure 1-1 shows the finite state machine of the Tracker and Table 1-5 shows the glossary and notes. The following states are defined in the state machine:

- STARTUP: When the Tracker is booting up, doing POSTs and other initializations, and getting ready to start LoRa network join attempts.
- DEEP SLEEP: The state explained in Section 1.3, where everything is in deep sleep (lowest energy state). It is possible to go to this state from any other state by pressing the sleep button on the Tracker board (labelled SW2). The Tracker always comes out of the factory in DEEP SLEEP. Applying a specific magnetic wake-up pattern to the magnet sign at the bottom of the Tracker will wake up the Tracker into STARTUP. The magnetic wake-up pattern has been specified in Section 1.3. Applying the same magnetic pattern in any state will reset the Tracker (basically triggering a transition to the STARTUP state).
- JOIN: When the Tracker is attempting to join a LoRa network.
- GNSS SEARCH: When the Tracker is attempting to acquire GNSS fixes and decide if it should transition to STILLNESS or MOBILITY state.
- GNSS DISABLED: The state where the GNSS has been disabled by the user (it is enabled by default).
- STILLNESS/MOBILITY: Ground speed is obtained from GNSS fixes. The average ground speed from all the fixes during the GNSS SEARCH state is compared to a threshold to determine whether the Tracker is mobile (transition to MOBILITY) or still (transition to STILLNESS. The speed thresholds for these two states are generally different (with the MOBILITY threshold larger than STILLNESS threshold) allowing for a hysteresis effect. GNSS fixes are reported with their corresponding periods in these two states. If the accelerometer and accelerometer assist are enabled (see Section 3.2.5), a transition to GNSS SEARCH occurs with every registered acceleration event and acceleration clear. If an acceleration event is registered, no more acceleration events are registered for at least a grace period, defined in Section 3.2.5.

Table 1-5: Legend for the ORCA Finite State Machine

Symbol	Controlled by Register	Definition
$T_S^{(GNSS)}$	0x 23	GNSS report period in STILLNESS state.
$T_M^{(GNSS)}$	0x 24	GNSS report period in MOBILITY state.
$T_D^{(BLE)}$	0x 25	BLE default report period.
$T_S^{(BLE)}$	0x 26	BLE report period in STILLNESS state.
$T_M^{(BLE)}$	0x 27	BLE report period in MOBILITY state.
S_{ground}	N/A	The 2-D ground speed calculated as the average ground speed from each fix obtained in the GNSS SEARCH state.
$S_{threshold}$	0x 31	Ground speed threshold for transitioning between MOBILITY and STILLNESS states. • When STILLNESS → GNSS SEARCH occurs: $S_{threshold} = S_{MOBILITY\ threshold}$ • When MOBILITY → GNSS SEARCH occurs: $S_{threshold} = S_{STILLNESS\ threshold}$ • When JOIN → GNSS SEARCH or GNSS DISABLED → GNSS SEARCH occurs: $S_{threshold} = \frac{S_{STILLNESS\ threshold} + S_{MOBILITY\ threshold}}{2}$
AcclAssist	0x 40	The Accelerometer Assist bit. This is the flag that controls whether an Accl Event or Accl Clear should cause a transition to the GNSS SEARCH state.
Accl Event	0x 42 0x 43 0x 44	When motion is detected and an acceleration alarm report is generated. Specifically, when the filtered (gravity-removed) value of any axis exceeds a configurable threshold (register 0x 44) a configurable number of times (register 0x 42) within a configurable period (register 0x 43).
Accl Clear	0x 45	When motion ends and an acceleration clear report is generated. Specifically, when no further above-threshold acceleration is registered for the duration of the grace period.
	N/A	Magnetic reset pattern.

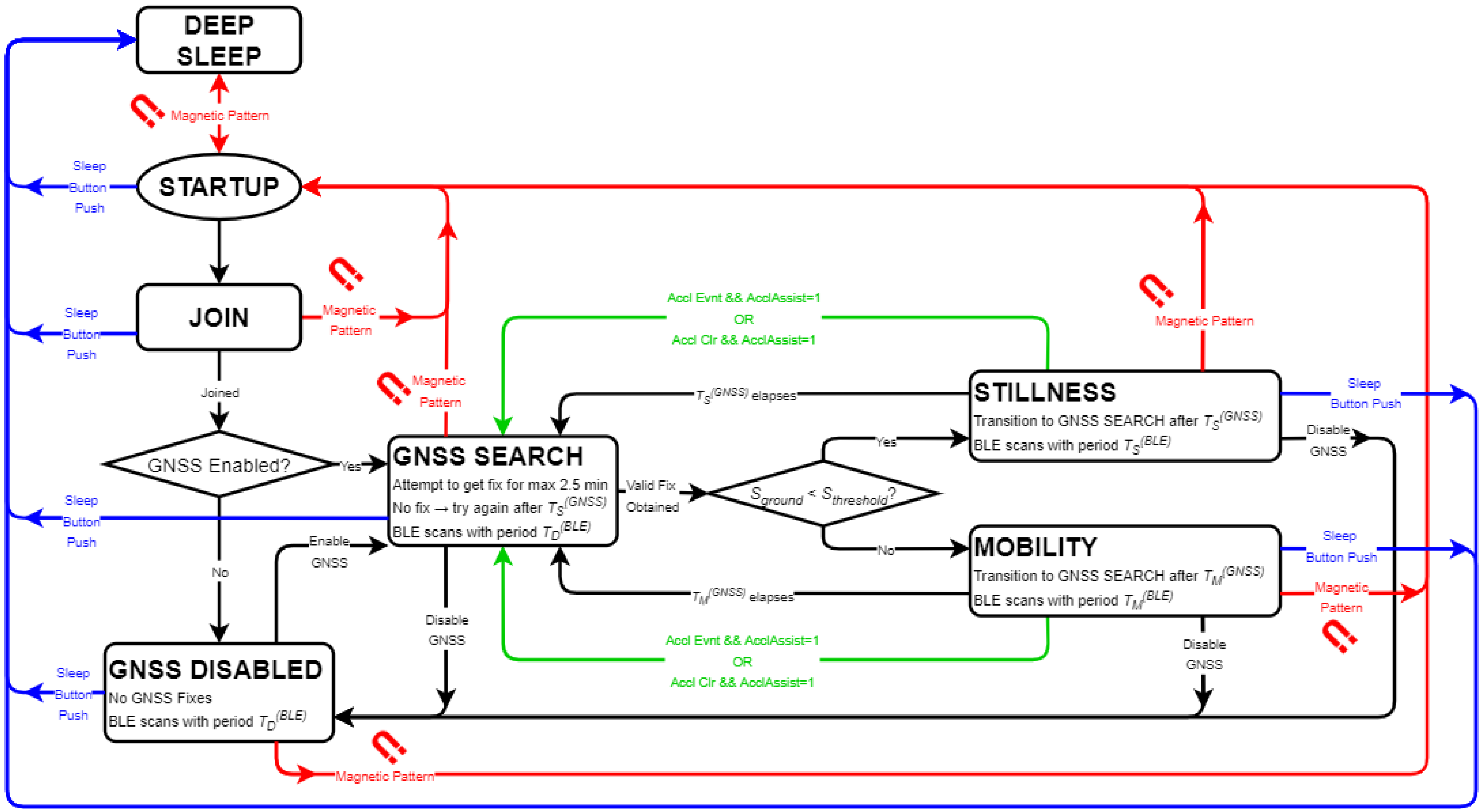


Figure 1-1: The ORCA Finite State Machine

1.2 BLE Operation

The BLE function of the Tracker when configured in Tracker (default) mode is Rx only; the Tracker only scans and does not advertise, which means it is not discoverable by other BLE-capable devices. During each scan, other 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 an UL.

The BLE scan can be disabled entirely or enabled at any time. Figure 1-2 shows the BLE scan scheme in the Tracker when the BLE scan is enabled. As shown in the figure, BLE scans are performed periodically with a configurable *scan period*. There are 3 different scan periods, each for a different internal device state. These scan periods are:

- $T_{\text{BLE, Default}}$ (in the GNSS DISABLED and GNSS SEARCH states).
- $T_{\text{BLE, Still}}$ (in the STILLNESS state).
- $T_{\text{BLE, Mobile}}$ (in the MOBILITY state).

Each scan duration is divided into *scan intervals*. The active BLE scan is performed only in the *scan window* portion of the scan interval. The ratio of the scan window to the scan interval is the *scan duty cycle*. 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 advertisements 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 BLE peripheral signals.

The scan period, duration, interval, and window are all configurable (see Sections 3.2.2 and 3.2.6).

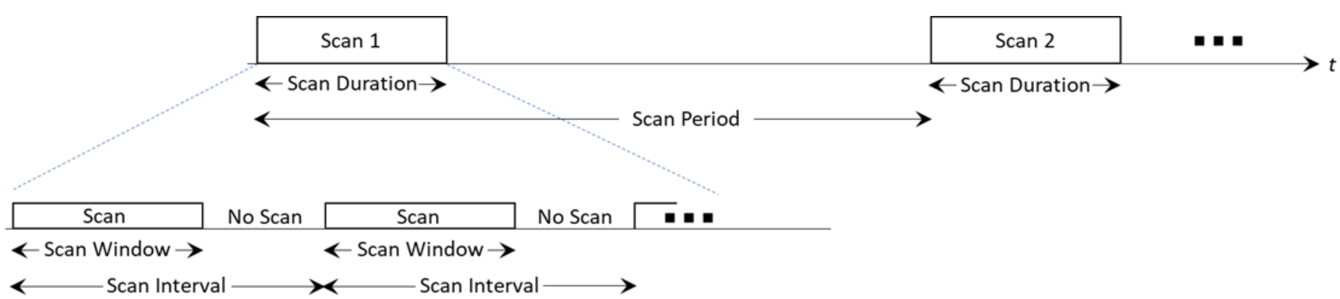


Figure 1-2: The BLE Scan Scheme

Reporting BLE devices can be performed in one of two possible reporting types: *basic* reporting or *filtered* reporting. In the basic (default) reporting, at the end of each scan duration, up to a maximum *N* discovered BLE devices are reported over LoRaWAN. In filtered reporting, up to maximum *N* discovered BLE from a user-specified list of favourable MAC addresses are reported.

This allows for keeping out undesired devices from the OTA report, and thus reducing the OTA time and saving battery life. An example application of this is for an indoor Beacon network; only the Beacon signals are of interest and not other devices like smartphones. In either reporting type, if no devices are found, an empty list is uplinked.

Reporting BLE devices can also be performed with the Repetition mode off (default) or on. Repetition refers to the fact that in each BLE scan, a single device can be typically observed (discovered) more than once. When the Repetition mode is off (default), only the last discovery is recorded for each device for possible future sorting and reporting. However, in some cases, it is useful to gather and report all data from a single device in a scan. By turning on the Repetition mode, ALL discovered devices, repetitive or not, are considered for possible reporting. As usual, the report can still be done with either basic or filtered reporting.

The Tracker supports BLE of Bluetooth 5.0. The BLE scan is performed in the passive mode only; i.e., the Tracker listens to surrounding peripherals, but does not transmit to them to request additional information.

NOTE: The BLE scan is exclusive to LoRa radio transmission; i.e., they do not overlap. If any reporting becomes due at the same time as a BLE scan, the reporting will be done after the BLE scan is complete.

1.3 Magnetic Reed Switch Operation

The Tracker is equipped with a magnetic reed switch. The reed switch can be operated by the provided magnet, and is used for the following purposes:

A. **Device Reset**:

This is mainly used to wake up the module from DEEP SLEEP and having it begin trying to join the network. When the Tracker exits the factory, it is in the low-power DEEP SLEEP mode[3] and can be activated using the specified magnetic pattern. The same magnetic pattern can just be used to reset the Tracker during normal operation, causing it to try to rejoin the network.

The magnetic pattern in this application is illustrated in Figure 1-3. A "magnet presence" is achieved by placing the magnet against the enclosure at the magnet symbol. A "magnet absence" is achieved by taking the magnet away from the enclosure. Figure 1-3 shows

[3] The Tracker will go to DEEP SLEEP whenever the internal sleep button on the PCBA (labeled SW2) is pressed. This is performed as the last step in the factory before closing the enclosure. The only ways to activate the module out of DEEP SLEEP is to apply the specified magnetic pattern or to open the enclosure and remove and reinsert the batteries [3].

that the pattern involves sustaining a "magnet presence" continuously for at least 3 s but less than 10 s.

When the specified magnetic pattern is applied to the Tracker, the Tracker displays an LED indication, described in Section 0, to show that it has accepted the magnetic pattern. In all cases, the magnet pattern causes the Tracker to reset. If the Tracker was in DEEP SLEEP when the pattern was applied, after resetting it will wake up and begin trying to join the network. If the Tracker was in normal operation when the magnet pattern was applied, after resetting it will try to rejoin the network.

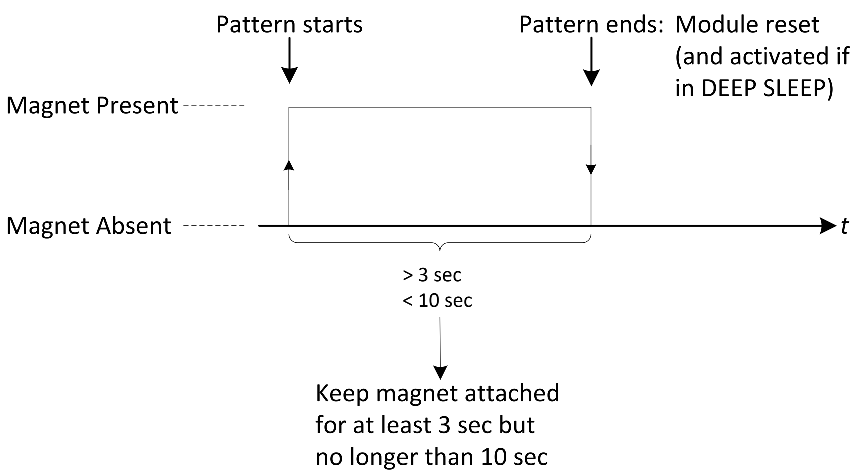


Figure 1-3: The Tracker Magnetic Reset/Wake-Up Pattern

B. **Forced UL**:

This is used to get the LoRaWAN Class-A Tracker to open a receive window so it can receive DL commands from the NS, or simply to trigger the Tracker to uplink some desired transducer data.

The magnetic pattern in this case is not user configurable, and involves attaching and taking away the magnet to and from the magnet sign at the bottom of the enclosure once, all in less than 2 sec, as shown in Figure 1-4. *It is important to note here that mistakenly holding the magnet attached to the module for more than 3 sec may trigger a device reset, as explained in item 1 above.*

It is configurable what is uplinked when such a reed switch event is registered. By default, the current FSM state of the Tracker is reported. Section 3.2.3 describes the configuration for the reed switch.

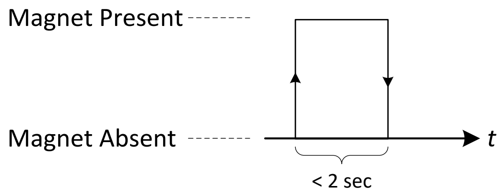


Figure 1-4: The Tracker Magnetic Forced UL Pattern

1.4 LEDs Behavior

The Tracker is equipped with two on-board LEDs: **GREEN** and **RED**. Their behaviour patterns reflect the internal device state and are described in the following subsections. The LED behaviour is not user configurable. Except during the situations described below, the LEDs are normally OFF during DEEP SLEEP or normal operation.

1.4.1 Power-On and Network Join Operation

When the Tracker is activated (woken up from DEEP SLEEP) or reset (either through a DL reset, magnet reset, or battery replacement), the following LED sequence occurs.

1. Both **GREEN** and **RED** are off for 10 seconds after any reset occurs (including a wakeup).
2. After 10 seconds, the Tracker SW will conduct its POST. When the POST ends, depending on the POST result:
   a. If the POST passes, **GREEN** and **RED** are switched ON for 1 second, as shown in Figure 1-5. After this, the Tracker will begin the join procedure as indicated by the LED pattern explained in step 3.
   b. If the POST fails, **GREEN** is toggled ON and OFF every 50 ms for 0.5 seconds, as shown in Figure 1-6. If this is the case, the Tracker will not go on to the join procedure in step 3 but will repeat the pattern in Figure 1-6 every 5-10 seconds indefinitely. A failed POST means the device is damaged in some way, and cannot normally function.

Figure 1-5: The GREEN and RED LED Pattern After a Successful POST

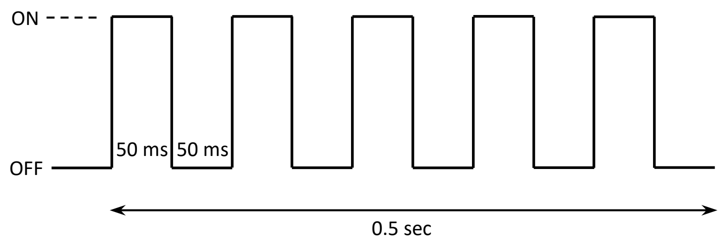


Figure 1-6: The GREEN LED Pattern After a Failed POST

3. After a successful POST, both **GREEN** and **RED** are turned off. Immediately following this, the Tracker will begin attempting to join the network:
    a. **GREEN** is toggled ON and OFF every 50 ms for the first hour. After that, it only flashes twice (ON time: 50 ms, OFF time: 50 ms) every 5 sec. This scheme has been shown in Figure 1-7.
    b. **RED** flashes just once:
        i. with a pulse duration of 25 ms right after transmitting a JOIN REQUEST.
        ii. with a pulse duration of 100 ms right after receiving a JOIN ACCEPT.

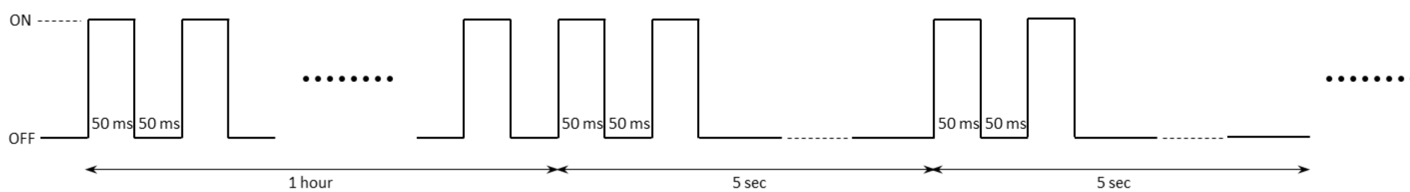


Figure 1-7: The GREEN LED Pattern During the Join Procedure

1.4.2 Normal Operation

After the Tracker has joined the network:

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

1.4.3 DEEP SLEEP

The Tracker displays an LED indication when it is brought out of DEEP SLEEP. The following LED pattern is displayed about 10 s after the pattern is applied:

1. **GREEN** is toggled ON and OFF every 0.5 sec for 3 sec as shown in Figure 1-8.

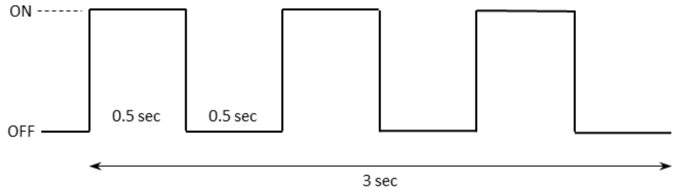


Figure 1-8: The GREEN LED Pattern Upon Waking from DEEP SLEEP

There is another similar LED pattern for when the device is put into DEEP SLEEP. After the DEEP SLEEP button is pressed, it will take 10 s for this LED pattern to occur:

1. **RED** is toggled ON and OFF every 0.1 sec for 0.6 sec as shown in Figure 1-9.

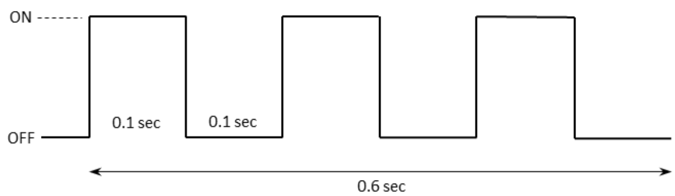


Figure 1-9: The RED LED Pattern Before Entering DEEP SLEEP

2 UL Payload Formats

The UL streams (from the Tracker to the NS) supported by the SW are shown in Table 2-1, and are explained in Sections 2.1 to 2.4. Refer to [2] for a comprehensive tool to decode Tracker UL frame payloads.

Table 2-1: UL Information Streams

Data Type	Sent on LoRaWAN Port
Real-time sensor data from the MCU, GNSS receiver, battery gauges, and accelerometer	**10**
Report GNSS logged (historical) time and position data	**15**
Report discovered BLE devices	**25**
Response to Configuration and Control Commands	**100**

2.1 Frame Payload to Report Real-Time Sensing Data

Each data field from the Tracker is encoded in a frame format shown in Figure 2-1. A big-endian format (MSb/MSB first) is always followed.

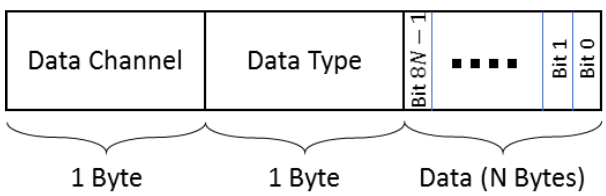


Figure 2-1: The Frame Format of the UL Payload

A Tracker message payload can include multiple data frames from different sensing entities in the Tracker. Frames can be arranged in any order. The Tracker frame payload values for present sensor data are shown in Table 2-2. In this table, the bit indexing scheme is as shown in Figure 2-1. Present sensor data in the UL are sent through ***LoRaWAN port 10***.

Table 2-2: UL Frame Payload Values for Tracker Data

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Battery 1 Status	0x01	0xBA	1 B	Unsigned	• Bits 0-6 = ($V_{Battery1}$–2.5 V) (10 mV/LSB) • Bit 7: EoS Alert[4] 0/1 = Inactive/Active	*battery1_status {* *voltage: <value>, (unsigned/V)* *eos_alert: <value> (unsigned/no unit)* *}*

[4] Not supported in SW 0.3.xx.

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Battery 2 Status	0x02	0xBA	1 B	Unsigned	• Bits 0-6 = ($V_{Battery2}$–2.5 V) (10 mV/LSB) • Bit 7: EoS Alert[5] 0/1 = Inactive/Active	*battery2_status { voltage: <value>, (unsigned/V) eos_alert: <value> (unsigned/no unit) }*
UTC	0x00	0x85	7 B	Timestamp (unsigned)	• Bits 40-55: Year [yyyy] • Bits 32-39: Month [1 to 12] • Bits 24-31: Day [1 to 31] • Bits 16-23: Hour [0 to 23] • Bits 8-15: Minute [0 to 59] Bits 0-7: Second [0 to 60][6]	*utc { year: <value>, (unsigned/no unit) month: <value>, (unsigned/no unit) day: <value, (unsigned/no unit) hour: <value>, (unsigned/no unit) minute: <value>, (unsigned/no unit) second: <value> (unsigned/no unit) }*
GNSS Position Coordinates	0x00	0x88	9 B	Coordinate (signed)	• Bits 48-71: Latitude (0.0000125°/LSB) [-90° to +90°] • Bits 16-47: Longitude (0.0000001°/LSB) [-180° to +180°] • Bits 0-15: Altitude (0.5 m/LSB) [-16384 m to +16383.5 m]	*coordinates { latitude: <value>, (signed/°) longitude: <value>, (signed/°) altitude: <value> (signed/m) }*
Ground Speed	0x00	0x92	2 B	Speed (unsigned)	0.1 m/s / LSB	*ground_speed: <value> (unsigned/m/s)*
FSM State	0x00	0x04	1 B	Counter Input	• 0 = GNSS DISABLED State • 1 = GNSS SEARCH State • 2 = STILLNESS State 3 = MOBILITY State	*fsm_state: <value> (unsigned/no unit)*

[5] Not supported in SW 0.3.xx.

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

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Fix Status	0x00	0x95	1 B	Bitmap Input	• Bit 0: 0/1 = UTC invalid/valid • Bit 1: 0/1 = Position invalid/valid Bits 2-7 = 0	*fix_status {* *utc: <value>, (unsigned/no unit)* *position: <value> (unsigned/no unit)* *}*
Geofence Status	0x01	0x95	1 B	Bitmap Input	• Bits 0-1 (Geofence 0): 0 = Unknown 1 = Inside 2 = Outside • Bits 2-3 (Geofence 1): 0 = Unknown 1 = Inside 2 = Outside • Bits 4-5 (Geofence 2): 0 = Unknown 1 = Inside 2 = Outside • Bits 6-7 (Geofence 3): 0 = Unknown 1 = Inside 2 = Outside	*geofence_status {* *num0: <value>, (unsigned/no unit)* *num1: <value>, (unsigned/no unit)* *num2: <value>, (unsigned/no unit)* *num3: <value> (unsigned/no unit)* *}*
Acceleration Alarm Status	0x00	0x00	1 B	Digital Input	• 0x00 = Alarm inactive 0xFF = Alarm active	*acceleration_alarm: <value> (unsigned/no unit)*
Acceleration Vector	0x00	0x71	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_vector {* *xaxis: <value>, (signed/g)* *yaxis: <value>, (signed/g)* *zaxis: <value> (signed/g)* *}*
Temperature	0x00	0x67	2 B	Temperature (signed)	0.1°C/LSB	*temperature: <value> (signed/°C)*

Examples:

- 0x 00 67 00 EC
  - $0x\ 00\ 67\ (\text{Temperature}) = (0x\ 00\ \text{EC}) \times 0.1°\text{C} = 23.6°\text{C}$

- 0x 00 67 FF FF 01 BA 63
  - $0x\ 00\ 67\ (\text{Temperature}) = (0x\ \text{FFFF}) \times 0.1°\text{C} = -0.1°\text{C}$
  - $0x\ 01\ \text{BA}\ (\text{Battery 1 Status})\text{: No EoS alert; voltage} = 2.5 + (0x\ 63) \times 0.01 = 3.49\ V$
- 0x 00 95 00 00 71 02 44 00 46 03 3E
  - $0x\ 00\ 95\ (\text{Fix Status}) = 0x\ 00 = \text{No valid UTC and position fix available}$
  - $0x\ 00\ 71\ (\text{Acceleration Vector}) = [\text{Xaxis: } (0x\ 02\ 44) \times 0.001g, \text{Yaxis: } (0x\ 00\ 46) \times 0.001g, \text{ Zaxis: } (0x\ 03\ 3\text{E}) \times 0.001g] = [\text{Xaxis: } 0.58g, \text{Yaxis: } 0.07g, \text{ Zaxis: } 0.83g]$
- 0x 00 88 3E 50 B0 BC 02 2D 60 08 2A
  - $0x\ 00\ 88\ (\text{Position Coordinates}) = [\text{Latitude: } (0x\ 3\text{E}\ 50\ \text{B}0) \times 0.0000125°, \text{Longitude: } (0x\ \text{BC}\ 02\ 2\text{D}\ 60) \times 0.0000001°, \text{ Altitude: } (0x\ 08\ 2\text{A}) \times 0.5\ m] = [\text{Latitude: } 51.0486°, \text{ Longitude: } -114.0708°, \text{ Altitude: } 1045\ \text{m}]$

2.2 Reporting GNSS Logged UTC and Position Data

The GNSS receiver in the Tracker logs GNSS information as time and position fixes are obtained. These fixes can be retrieved later from the GNSS receiver flash and reported OTA on ***LoRaWAN port 15***. The GNSS log to be reported comprises several log entries. Each log entry consists of a pair of corresponding UTC (as the timestamp) and position coordinates.

The payloads to report these log entries are in one of three formats shown in Figure 2-2. Formats (a) and (b) are for payloads that contain only one timestamp or one set of position coordinates. Corresponding timestamp and position coordinates have the same log fragment number. Using formats (a) and (b), two payloads, one of format (a) and one of format (b), are needed to report one log entry.

For example, successive payloads “0x 01 00 U0”, “0x 02 00 P0”, “0x 01 01 U1”, “0x 02 01 P1”, “0x 01 02 U2”, “0x 02 02 P2” can be sent to report log entries (U0, P0), (U1, P1), (U2, P2), where U denotes UTC and P denotes position information.

Format (c) is for payloads that contain one or more log entries. Depending on the UL DR, a GNSS log may be reported only by payloads of formats (a) and (b), or only by payloads of format (c), or by a combination of these formats. Log fragment numbers help the NS to reconstruct the log in its original order.

For example, payload “0x 03 00 U0 P0 U1 P1 U2 P2” can be sent to report log entries (U0, P0), (U1, P1), (U2, P2), where U denotes UTC and P denotes position information.

A payload consisting of only a one-byte Data Type 0x00 is transmitted to indicate there is no log entry available to report.

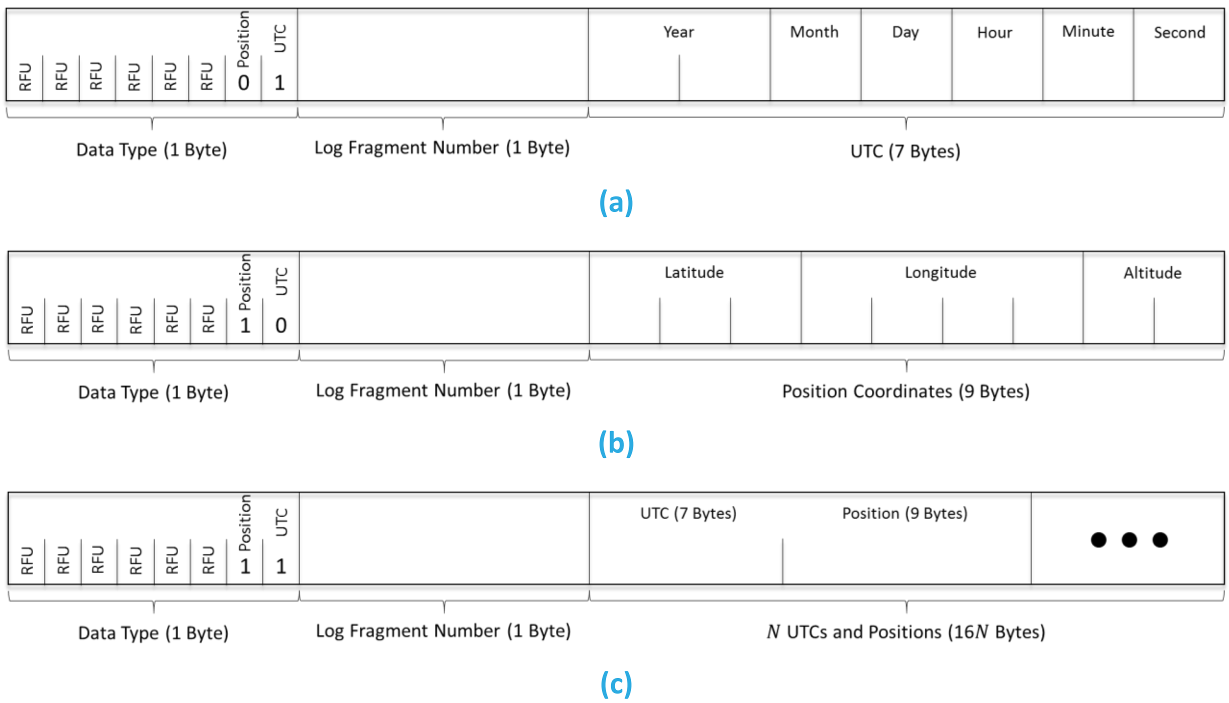


Figure 2-2: The UL payload formats to report GNSS logs.

2.3 Reporting Discovered BLE Devices

For information about how BLE scans are conducted and how discovered device data is handled, see Section 1.2.

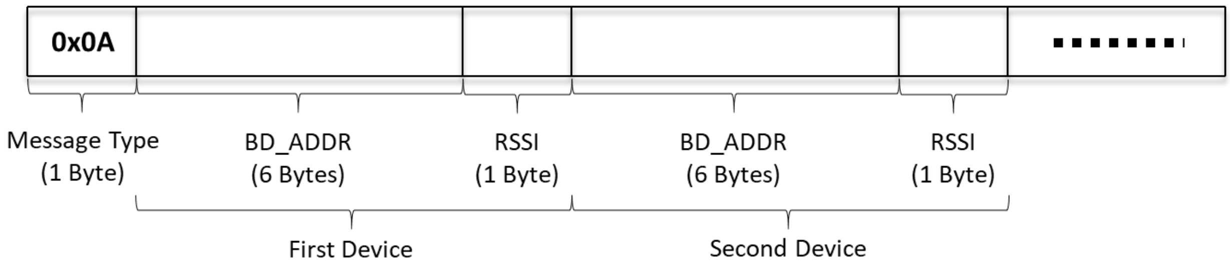
Discovered BLE devices are reported on ***LoRaWAN port 25***. The payload format to report such devices has been shown in the diagrams in Figure 2-3.

With *basic* reporting enabled (Figure 2-3-(a)), the message type header is 0x0A. The BD_ADDR for each discovered device is a full 6-byte MAC address, and is followed by the device RSSI, which is a signed one-byte number.

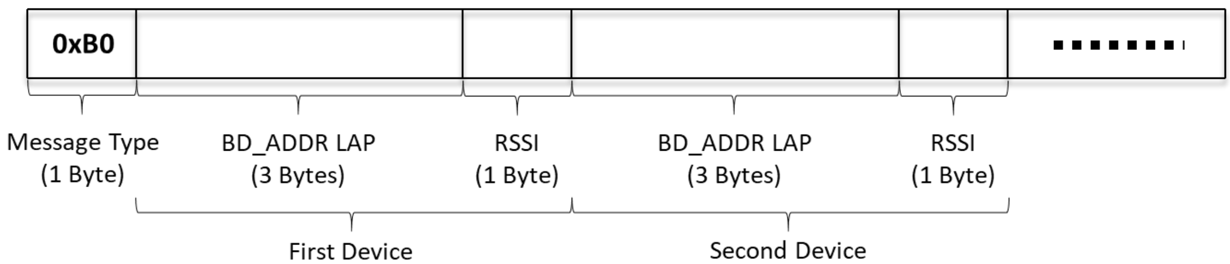
With *filtered* reporting (Figure 2-3-(b)–(e)), up to 4 ranges of BD_ADDR can be defined for filtering discovered devices (see Section 3.2.6). The message type headers 0xB0, 0xB1, 0xB2, and 0xB3 correspond to Ranges 0, 1, 2, and 3, respectively. A BD_ADDR consists of an *Organizationally-Unique Identifier* (OUI) comprising the 3 MSBs followed by a *Lower Address Part* (LAP) comprising the 3 LSBs. Each BD_ADDR range is a 9-byte OUI:LAP_{start}-LAP_{end} that determines the range of BD_ADDRs as OUI:LAP_{start} to OUI:LAP_{end}. Therefore, OUI is the same and known for all devices in each range. In fact, the message type header determines the range, and thus the OUI for all devices in the message, such that the devices in each message can be uniquely identified by their LAPs only.

For example, if the only discoverable BLE devices of interest all have MAC addresses that begin with AC233F (OUI) and only the last 3 bytes are different for each device (LAPs), the BD_ADDR range to filter for only these devices would be AC233F:000000-FFFFFF. In other words, this BD_ADDR range means that the Tracker will filter the discovered devices to include only those with MAC addresses from AC233F000000 to AC233FFFFFFF, inclusive.

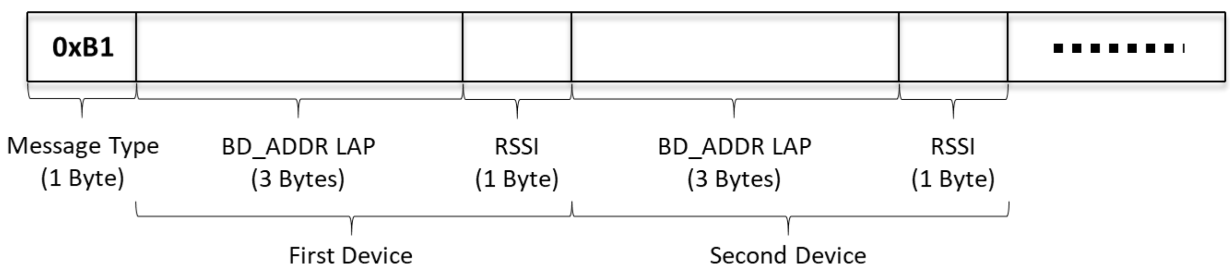
Zero, one, or more devices can be reported in a single message, depending on the number of devices available to report and payload size limitation as determined by LoRaWAN regional parameters [3]. See Section 1.2 for how many and what devices are chosen to get reported OTA. The case of zero devices (an empty BLE device list) happens when no devices are discovered, or when the BLE is disabled (see Section 3.2.6) but a BLE report is due. If there are more devices to be reported than can fit into one message, more than one UL will be subsequently transmitted to report all *N* devices.



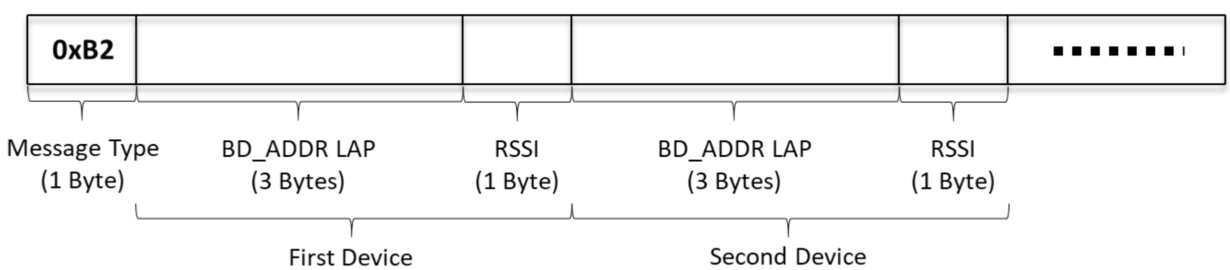
(a) Basic reporting.



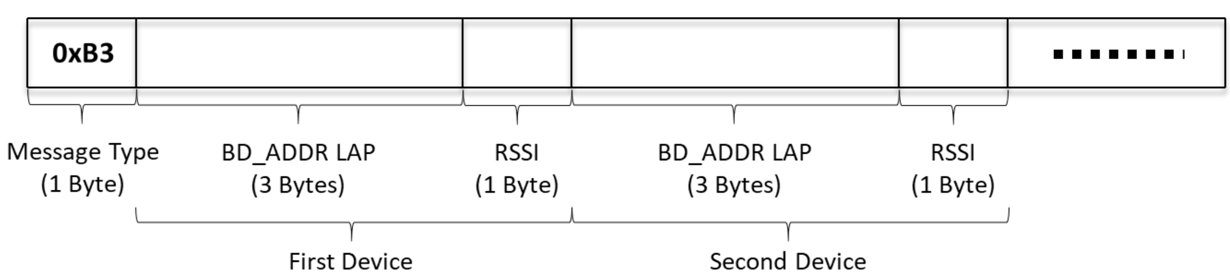
(b) Filtered reporting, Range 0.



(c) Filtered reporting, Range 1.



(d) Filtered reporting, Range 2.



(e) Filtered reporting, Range 3.

Figure 2-3: The UL payload format to report discovered BLE devices.

2.4 Response to Configuration and Control Commands

Tracker responses to DL configuration and control commands (which are sent on LoRaWAN port 100; see Section 3.2) are sent in the UL on ***LoRaWAN port 100***. These responses include:

- Returning the value of a configuration register in response to a query from a DL read command.
- Returning an acknowledgement after a successful reconfiguration of a register(s) following a DL write command.

In the former case, the Tracker responds by the address and value 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).

In the latter case, the Tracker 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 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 Tracker response in the former case).

3 DL Payload Formats

The DL streams (from the NS to the Tracker) supported by the SW are shown in Table 3-1, and are explained in Sections 3.1 and 3.2. Refer to [2] for a comprehensive tool to encode DL messages into DL frame payloads.

Table 3-1: DL Information Streams

Data Type	Sent on LoRaWAN Port
Request GNSS logged (historical) UTC and position	**15**
Configuration and Control Commands	**100**

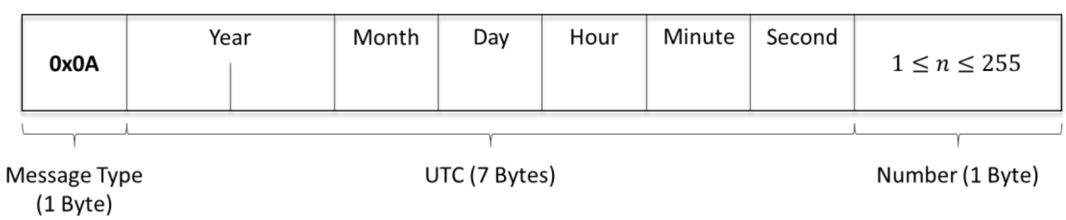
3.1 Request GNSS Log

The request from the user to receive the GNSS log is sent on ***LoRaWAN port 15***. This request can be sent in two types; Type A or Type B. Figure 3-1 shows the payload format in each request type. The first byte in each payload is the request type (i.e. 0x0A or 0x0B).

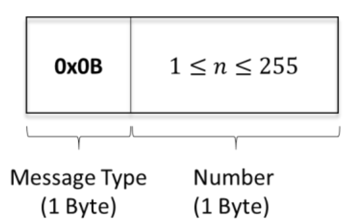
In the Type A request, a UTC timestamp t, and a number n, where $1 \leq n \leq 255$, as shown in Figure 3-1 is given. By sending this request, the user is telling the Tracker to retrieve n GNSS log entries (time and position fixes) before time t from the logged historical data.

In the Type B request, only a number n, where $1 \leq n \leq 255$ is given. By sending this request, the user is telling the Tracker to retrieve the last (most recent) n GNSS log entries (time and position fixes).

Upon receiving a GNSS log request, the Tracker responds with the requested GNSS log on port 15, as explained in Section 2.2. If there is no log as per the request available, the zero-byte 0x00 is uplinked by the Tracker, as specified in Section 2.2.



(a) Type A request.



(b) Type B request.

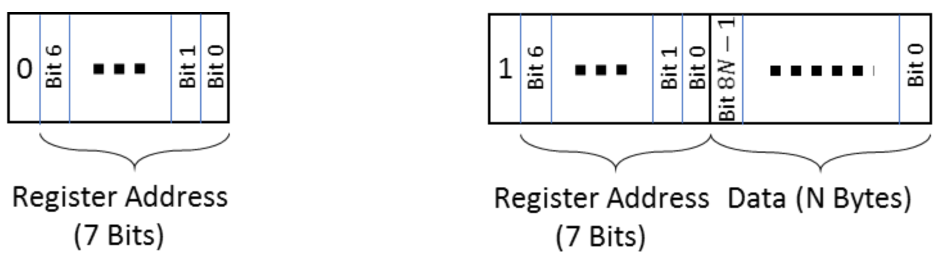
Figure 3-1: The DL payload format to request GNSS log.

3.2 Configuration and Control Commands

Configuration and control commands are used to query current device settings, reconfigure device settings, or tell the device to perform some action. All configuration and control commands are sent in reference to one or more *configuration register*. Each register has an *address* that is linked to a particular setting or action. These addresses are bound between 0x00 and 0x7F.

A single DL configuration and control message can contain multiple command blocks, with a possible mix of read and write commands. Each message block is formatted as shown in Figure 3-2. A big-endian format (MSB first) is always followed.

Bit 7 of the first byte determines whether a read or write action is being performed, as shown in Figure 3-2. All read commands are one-byte long. 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.



(a) The read command. (b) The write command.

Figure 3-2: The format of a DL configuration and control message block.

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

Examples:

- Read Registers 0x10, 0x11, and 0x12:
  - DL command: { 0x 10 11 12 }
- Read Register 0x13 and Write value 0x8000 to Register 0x10:
  - DL command: { 0x 13 90 80 00 }

When a write command is sent to the Tracker, the Tracker immediately responds with a CRC32 of the entire DL payload as the first 4 bytes of the UL frame on ***LoRaWAN port 100*** (also see Section 2.4).

DL configuration and control commands fall into one of the following categories and are discussed in Sections 3.2.1–3.2.8:

- LoRaMAC Configuration
- Periodic Tx Configuration

- Reed Switch Configuration
- GNSS Configuration
- Accelerometer Configuration
- BLE Configuration
- Temperature Threshold Configuration
- Command and Control

3.2.1 LoRaMAC Configuration

LoRaMAC options can be configured using the LoRaWAN DL. These configuration options change the default MAC configuration that the Tracker loads on start-up. They can also change certain run-time parameters. Table 3-2 shows the MAC configuration registers. In this table, the bit indexing scheme is as shown in Figure 3-2. All the registers have R/W access.

Table 3-2: LoRaMAC Configuration Registers

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x10	Join Mode	2 B	• Bit 15: 0/1 = ABP/OTAA mode • Bits 0-14: Ignored	OTAA mode **0x80 00**	*loramac_join_mode:* *<value>* *(unsigned/no unit)*
0x11	Options	2 B	• 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 • Bit 3: 0/1 = ADR disabled/enabled • Bits 4-15: Ignored	• Unconfirmed UL • Public Sync Word • Duty cycle enabled[7] • ADR enabled **0x00 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)* *}*

[7] In the LoRa RF regions where there is no duty cycle limitation, such as US915, the "enabled duty cycle" configuration of the Sensor is ignored.

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x12	DR and Tx Power[8]	2 B	• 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 3-3) **0x00 00**	*loramac_dr_tx { dr_number: <value>, (unsigned/no unit) tx_power_number: <value> (unsigned/no unit) }*
0x13	Rx2 Window	5 B	• Bits 8-39: Channel frequency in Hz for Rx2 • Bits 0-7: DR for Rx2	As per Table 3-4	*loramac_rx2 { frequency: <value>, (unsigned/Hz) dr_number: <value> (unsigned/no unit) }*

Table 3-3: Default Maximum Tx Power in Different Regions

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

Table 3-4: Default Values of Rx2 Channel Frequency and DR Number in Different Regions

RF Region	Channel Frequency [Hz]	DR Number
EU868	869525000	0
US915	923300000	8
AS923	923200000	2
AU915	923300000	8
IN865	866550000	2
KR920	921900000	0
RU864	869100000	0

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

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

3.2.1.1 LoRa Configuration DL Examples

- Switch Device to ABP Mode:
  - DL payload: { 0x 90 00 00 }
- Set ADR On, No Duty Cycle, and Confirmed UL Payloads:
  - DL payload: { 0x 91 00 0B }
- Set default DR number to 3, default Tx power number to 4:
  - DL payload: { 0x 92 03 04 }

3.2.2 Periodic Tx Configuration

All periodic reporting is synchronized around ticks. The *core tick* is simply a user-configurable time base unit that is used to schedule Tracker measurements. For each transducer in the Tracker, the number of elapsed ticks before transmitting can be defined. Table 3-5 shows a list of registers used to configure the Tracker periodic transmissions. All the registers have R/W access.

The reporting period for each transducer is obtained as per the following:

<Transducer> ***Reporting Period*** $=$ ***Seconds per Core Tick*** $\times$ ***Ticks per*** **<Transducer>**,

where <Transducer> can be “Battery”, “GNSS in STILLNESS State”, “GNSS in MOBILITY State”, “Accelerometer”, “BLE in DEFAULT State”, “BLE in STILLNESS State”, “BLE in MOBILITY State”, “Temperature”, or “FSM State”, as shown in Table 3-5. If <Transducer> *Reporting Period* equals 0, it means that the <Transducer> periodic reporting is disabled. This happens when Ticks per <Transducer> is equal to 0.

Table 3-5: Periodic Transmission Configuration Registers

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x20	Seconds per Core Tick	4 B	• Tick value for periodic events • Acceptable values: 3, 4, …, 86400 • Other values: Invalid and ignored	3600 seconds = 1 hour **0x00 00 0E 10**	*seconds_per_core_tick: <value> (unsigned/sec)*
0x21	Ticks per Battery	2 B	• Ticks between battery reports • 0 disables periodic battery reports	24 ticks = 1-day period **0x00 18**	*ticks_per_battery: <value> (unsigned/no unit)*

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x 22	Ticks per GNSS in STILLNESS State	2 B	• Ticks between GNSS reports in STILLNESS state • 0 disables periodic GNSS reports in STILLNESS state	1 tick = 1-hour period **0x00 01**	*ticks_per_gnss_stillness: <value> (unsigned/no unit)*
0x 23	Ticks per GNSS in MOBILITY State	2 B	• Ticks between GNSS reports in MOBILITY state • 0 disables periodic GNSS reports in MOBILITY state	1 tick = 1-hour period **0x00 01**	*ticks_per_gnss_mobility: <value> (unsigned/no unit)*
0x 24	Ticks per Accelerometer	2 B	• Ticks between accelerometer reports • 0 disables periodic accelerometer reports	Periodic reporting disabled **0x00 00**	*ticks_per_accelerometer: <value> (unsigned/no unit)*
0x 25	Ticks per BLE in DEFAULT State	2 B	• Ticks between BLE reports in DEFAULT (GNSS DISABLED or GNSS SEARCH) state • 0 disables periodic BLE reports in DEFAULT state	6 ticks = 6-hour period **0x00 06**	*ticks_per_ble_default: <value> (unsigned/no unit)*
0x 26	Ticks per BLE in STILLNESS State	2 B	• Ticks between BLE reports in STILLNESS state • 0 disables periodic BLE reports in STILLNESS state	6 ticks = 6-hour period **0x00 06**	*ticks_per_ble_stillness: <value> (unsigned/no unit)*
0x27	Ticks per BLE in MOBILITY State	2 B	• Ticks between BLE reports in MOBILITY state • 0 disables periodic BLE reports in MOBILITY state	6 ticks = 6-hour period **0x00 06**	*ticks_per_ble_mobility: <value> (unsigned/no unit)*
0x28	Ticks per Temperature	2 B	• Ticks between temperature reports • 0 disables periodic temperature reports	Periodic reporting disabled **0x00 00**	*ticks_per_temperature: <value> (unsigned/no unit)*
0x29	Ticks per FSM State	2 B	• Ticks between FSM state reports • 0 disables periodic FSM state reports	Periodic reporting disabled **0x00 00**	*ticks_per_fsm_state: <value> (unsigned/no unit)*

NOTE: For best results it is not recommended to set the GNSS report period in STILLNESS or MOBILTITY to less than 2 min. Also, refer to Section ▯ regarding precautions regarding how small to set the BLE report period in DEFAULT, STILLNESS, or MOBILITY.

3.2.2.1 Periodic Configuration DL Examples

- Read current value of Seconds per Core Tick:

  - DL payload: { 0x 20 }
    - Reg 20 with the write bit set to false
- Report Temperature every core tick:
  - DL payload: { 0x A8 00 01 }
    - Reg 28 with its write bit set to true
    - Ticks per Temperature set to 1 (one)

3.2.2.2 Best Practice for Configuring GNSS and BLE Reporting Periods

For GNSS reporting, it is recommended that the reporting periods for GNSS in both STILLNESS (register 0x 22) and MOBILITY (register 0x 23) states not be configured to less than 3 minutes. This is for 2 reasons:

- GNSS searches and the uplinking of the results are processes that consume a large amount of energy. The more frequent these occur, the more the battery life will decrease.
- The Tracker will attempt to acquire satellite data in the GNSS SEARCH state until it either gets a valid fix or a 2.5-minute timeout elapses. After one of these occurs, the results of the search is sent in an UL report. The time it takes to get a valid fix depends on the strength of the GNSS signal, and if there is no GNSS signal the 2.5-minute timeout will expire. Therefore, if the Tracker is in a location where the GNSS signal is poor or nonexistent (e.g. inside buildings), the actual GNSS report period may be greater than expected if configured for less than 3 minutes.
  In other words, the device may not report GNSS data according to the configured periods if the configured periods are less than 3 minutes and the Tracker is located in a poor-GNSS signal area.

For BLE report period recommendations, refer to Section 3.2.6.4.

3.2.2.3 Anti-Bricking Strategy

Since the magnetic reed switch functionality cannot be disabled (see Sections 1.3 and 3.2.3), it is impossible to completely brick the Tracker with a bad configuration; i.e., it is always possible to trigger the Tracker to uplink something so it can receive DL commands for a desired configuration change. However, there are use cases in which using a magnet to trigger the Tracker may not be convenient or even possible, e.g. due to special mounting or volume of deployed Trackers.

To address scenarios where the reed switch cannot be relied upon to avoid bricking the Tracker, the SW on the Tracker always takes the following strategy:

After any configuration change on registers 0x21 to 0x29, if all periodic reporting becomes disabled, or the minimum period in enabled periodic reporting becomes larger than a day (86,400 sec), then register 0x21 is automatically set to the largest value that makes the battery

reporting period smaller than or equal to 1 day; i.e. the value of register 0x21 is set to $\left\lfloor \frac{86400}{\text{Value of register } 0x20} \right\rfloor$***, where*** $\lfloor . \rfloor$ ***is the floor function.***

3.2.3 Magnetic Reed Switch Configuration

The Tracker is triggered to send a forced uplink whenever the above magnet event is registered (the operation of the reed switch has been described in Section 1.3). They type of data sent in such an uplink is configurable but by default reports the current FSM state. The reed switch functionality cannot be disabled.

Table 3-6 shows the configuration register for the reed switch. In this table, the bit indexing scheme is as shown in Figure 3-2. This register has R/W access.

Bits 0-5 of the Value to Tx register determine what the Tracker transmits when a magnet event is registered. The battery, acceleration vector, temperature, discovered BLE devices, GNSS log entry, and FSM state are all reported using their usual uplink formats explained in Section 2.

Table 3-6: Magnetic Reed Switch Configuration Register

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x2A	Value to Tx	2 B	• Bit 0: 0/1 = Battery report disabled/enabled • Bit 1: 0/1 = Acceleration vector report disabled/enabled • Bit 2: 0/1 = Temperature report disabled/enabled • Bit 3: 0/1 = BLE report disabled/enabled • Bit 4: 0/1 = Last GNSS log entry report disabled/enabled • Bit 5: 0/1 = FSM state report disabled/enabled • Bits 6-15: Ignored	FSM State Reported **0x00 20**	*reed_switch_tx {* *battery: <value>, (unsigned/no unit)* *acceleration_vector: <value>, (unsigned/no unit)* *temperature: <value>, (unsigned/no unit)* *ble: <value>, (unsigned/no unit)* *gnss_log: <value>, (unsigned/no unit)* *fsm_state: <value> (unsigned/no unit)* *}*

NOTE: IF

{ bit 0 is set to 0 } AND

{{ bit 1 is set to 0 } OR { the accelerometer is disabled (bit 7 of register 0x40 is 0) }} AND

{ bit 2 is set to 0 } AND

{{ bit 3 is set to 0 } OR { BLE is disabled (register 0x50 is 0) }} AND

{{ bit 4 is set to 0 } OR { GNSS is disabled (bit 7 of register 0x30 is 0) }} AND

{ bit 5 is set to 0 },

THEN an ***empty uplink*** is transmitted on port 10 upon registration of a magnet event.

The feature of triggering the Tracker to send an uplink by using a magnet cannot be disabled.

3.2.3.1 Magnetic Reed Switch Configuration DL Examples

- Read current value of *Value to Tx*:
  - DL payload: { 0x 2A }
    - Reg 2A with the write bit set to false
- Report BLE data with every magnet trigger:
  - DL payload: { 0x AA 00 08 }
    - Reg 2A with its write bit set to true
    - Bit 3 set to 1
    - All other bits set to 0

3.2.4 GNSS Configuration

Table 3-7 shows a list of configuration registers for the Tracker's GNSS receiver. In this table, the bit indexing scheme is as shown in Figure 3-2. All the registers have R/W access.

Table 3-7: GNSS Receiver Configuration Registers

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x30	Mode	1 B	• Bits 0-6: Ignored • Bit 7: 0/1 = GNSS receiver disabled/enabled	GNSS receiver enabled **0x80**	*gnss_enabled: <value>* *(unsigned/no unit)*
0x31	Ground Speed Thresholds	2 B	• Bits 8-15: Mobility Ground Speed Threshold (0.1 m/s / LSB) • Bits 0-7: Stillness Ground Speed Threshold (0.1 m/s / LSB) • Mobility Threshold ≤ Stillness Threshold: Invalid and ignored	• Mobility threshold = 3 m/s • Stillness threshold = 1 m/s **0x1E 0A**	*speed_threshold {* *mobility: <value>, (unsigned/m/s)* *stillness: <value> (unsigned/m/s)*

					}
0x33	Value to Tx	1 B	• Bit 0: 0/1 = UTC report disabled/enabled • Bit 1: 0/1 = Position Coordinates report disabled/enabled • Bit 2: 0/1 = Ground Speed report disabled/enabled • Bit 3: 0/1 = Geofence Status report disabled/enabled • Bits 0-3 = 0: Invalid and ignored • Bits 4-7: Ignored	UTC and Position Coordinates reports enabled **0x03**	*gnss_tx {* *utc: <value>, (unsigned/no unit)* *coordinates: <value>, (unsigned/no unit)* *ground_speed: <value>, (unsigned/no unit)* *geofence: <value> (unsigned/no unit)* *}*
0x34	Geofence 0 Definition	8 B	• Bits 40-63: Center Latitude (0.0000125°/LSB) [-90° to +90°] • Bits 16-39: Center Longitude (0.000025°/LSB) [-180° to +180°] • Bits 0-15: Radius (10 m/LSB)	Geofence 0 Inactive **0x00 00 00 00 00 00 00 00**	*geofence0 {* *latitude: <value>, (signed/°)* *longitude: <value>, (signed/°)* *radius: <value> (unsigned/m)* *}*
0x35	Geofence 1 Definition	8 B	• Bits 40-63: Center Latitude (0.0000125°/LSB) [-90° to +90°] • Bits 16-39: Center Longitude (0.000025°/LSB) [-180° to +180°] • Bits 0-15: Radius (10 m/LSB)	Geofence 1 Inactive **0x00 00 00 00 00 00 00 00**	*geofence1 {* *latitude: <value>, (signed/°)* *longitude: <value>, (signed/°)* *radius: <value> (unsigned/m)* *}*
0x36	Geofence 2 Definition	8 B	• Bits 40-63: Center Latitude (0.0000125°/LSB) [-90° to +90°] • Bits 16-39: Center Longitude (0.000025°/LSB) [-180° to +180°] • Bits 0-15: Radius (10 m/LSB)	Geofence 2 Inactive **0x00 00 00 00 00 00 00 00**	*geofence2 {* *latitude: <value>, (signed/°)* *longitude: <value>, (signed/°)*

					radius: <value> *(unsigned/m)* *}*
0x37	Geofence 3 Definition	8 B	• Bits 40-63: Center Latitude (0.0000125°/LSB) [-90° to +90°] • Bits 16-39: Center Longitude (0.000025°/LSB) [-180° to +180°] • Bits 0-15: Radius (10 m/LSB)	Geofence 3 Inactive **0x00 00 00 00 00 00 00 00**	*geofence3 {* *latitude: <value>, (signed/°)* *longitude: <value>, (signed/°)* *radius: <value> (unsigned/m)* *}*

3.2.4.1 Mode

The GNSS receiver can be powered off/on to tune power usage (battery life) for end-user applications.

NOTE: If the GNSS receiver is disabled, no periodic or event-based report related to GNSS are produced.

3.2.4.2 Ground Speed Thresholds

Register 0x31 defines Mobility and Stillness Ground Speed Thresholds. The GNSS receiver obtains (2-D) ground speed of the Tracker as part of each fix. When the Tracker is in the STILLNESS/MOBILITY state, and an average over the ground speeds is above/below the Mobility/Stillness Ground Speed Threshold, a transition to the MOBILITY/STILLNESS state occurs.

This transition scheme, with the fact that Mobility Ground Speed Threshold must be greater than Stillness Ground Speed Threshold, provides a hysteresis effect to avoid frequent transitions due to noisy speed measurements.

For the Tracker in the SEARCH state, the ground speeds averaged over 15 consecutive fixes acquired in 15 s is compared with:

$$(\text{Mobility Ground Speed Threshold} + \text{Stillness Ground Speed Threshold})/2;$$

if larger, a transition to MOBILITY occurs. If smaller, a transition to STLLNESS occurs.

3.2.4.3 Value to Tx

When the GNSS receiver is periodically polled, the data to transmit can be configured by the end user. Available types are:

- UTC: UTC time fix in year, month, day, hour, minute, and second.
- Position Coordinates: latitude, longitude, and altitude of the obtained fix.

- Ground Speed: Ground speed of the Tracker in multiples of 0.1 m/s
- Geofence Status: Obtained fix status as being "unknown", "inside", or "outside" relative to each geofence—Geofence Status for undefined geofences returns 0 (equivalent to "unknown").

NOTE: A single GNSS Fix Status message (with header 0x 00 95, as shown in Section 2.1) is automatically transmitted if UTC or Position Coordinates or both is/are enabled (i.e. supposed to be reported) but is/are not available at the time of reporting.

3.2.4.4 Geofence Definition Registers

Geofences are virtual perimeters that define the boundary between 2 areas of interest: inside the geofence or outside the geofence. These are useful for defining and monitoring special geographical regions by allowing the Tracker to send status information about whether it is located inside or outside of a geofence, or if the status is unknown.

The *Geofence Definition* registers are used to define up to 4 geofences that can be activated on a Tracker. Each geofence area is a circle and is defined by the latitude and longitude of its center and its radius.

By default, the values of these registers are 0 (all geofences are inactive). Whenever the user defines one or more geofences by updating the value of one or more of these registers, the Tracker SW sets the corresponding geofence in the GNSS receiver.

Whenever the GNSS receiver is polled to return the geofence status, it will return the status of all geofence areas, which the Tracker subsequently reports OTA (using the header 0x 01 95 followed by 1 byte data, as indicated in Section 2.1).

3.2.4.5 GNSS Configuration DL Examples

- Read current value of *GNSS Mode*:
  - DL payload: { 0x 30 }
    - Reg 30 with the write bit set to false
- Disable UT and coordinate reporting and enable ground speed reporting:
  - DL payload: { 0x B2 04 }
    - Reg 32 with its write bit set to true
    - Bit 3 set to 1
    - All other bits set to 0

3.2.5 Accelerometer Configuration

The main objective of the accelerometer in the Tracker is to detect motion by either periodic sampling or threshold detection. The DC-component of the acceleration is filtered out by use of an always-enabled high-pass filter. That is, the nominal, ever-constant 1 *g* due to gravity is always removed. I.e. if the Tracker is motionless sitting on a surface, the output on all axes is 0 *g*. The accelerometer supports both periodic-based and event-based reporting, and can optionally be disabled altogether (reg 0x40).

In the case of periodic-based reporting, only the acceleration vector (X-axis, Y-axis, Z-axis) is reported, with the period configured via registers 0x20 and 0x24 (see Section 3.2.2). Registers 0x20 and 0x24 can also be used to disable the periodic reporting.

In the case of event-based reporting, an acceleration event is registered whenever the filtered (gravity-removed) value of any axis exceeds a configurable threshold (register 0x44) for a configurable number of times (register 0x42) within a configurable period (register 0x43). For example, using default configuration settings, as soon as the acceleration magnitude on any axis is measured to be greater than 0.8 *g* (register 0x44, *Acceleration Event Threshold*) one time (register 0x42, *Acceleration Event Threshold Count*) in less than 10 seconds (register 0x43, *Acceleration Event Threshold Period*), an acceleration alarm “motion detected” UL is sent.

An acceleration alarm is considered “cleared” as soon as no further above-threshold acceleration is registered for at least a configurable *grace period* (register 0x45). No additional acceleration alarms are sent before an acceleration clear is registered. For example, after an acceleration event has been registered, the Tracker must not sustain any above-threshold movement for the full 5-minute (default) grace period before an acceleration clear is registered. Until that time, no additional acceleration alarm ULs are sent. Every time an above-threshold acceleration is measured after a registered accelerometer event but before that event has been cleared, the grace period timer resets.

Registered acceleration events and clears are reported OTA by raising acceleration alarm ULs. The UL payload is **0x00 00 FF** if motion is detected (acceleration event) and **0x00 00 00** if the motion has stopped (acceleration clear). These acceleration alarms can be disabled or enabled via register 0x46.

If *Accelerometer Assist* is enabled (register 0x40), then both acceleration events and accelerometer clears trigger a switch to the GNSS SEARCH state, followed by an UL containing the GNSS results of that search. In other words, Accelerometer Assist triggers a GNSS report when the Tracker begins to move and when it stops moving.

Table 3-8 shows a list of accelerometer configuration registers. In this table, the bit indexing scheme is as shown in Figure 3-2. All the registers have R/W access.

Table 3-8: Accelerometer Configuration Registers

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x40	Mode	1 B	• Bit 0/1/2: 0/1 = X/Y/Z-axis disabled/enabled • Bit 6: 0/1 = Accelerometer Assist disabled/enabled • Bit 7: 0/1 = Accelerometer off/on • Bits 3-5: Ignored	• X-axis enabled • Y-axis enabled • Z-axis enabled • Accelerometer Assist enabled • Accelerometer on **0xC7**	*accelerometer_mode {* *xaxis_enabled: <value>, (unsigned/no unit)* *yaxis_enabled: <value>, (unsigned/no unit)* *zaxis_enabled: <value>, (unsigned/no unit)* *assist_enabled: <value>, (unsigned/no unit)* *poweron: <value> (unsigned/no unit)* *}*
0x41	Sensitivity	1 B	• Bits 0-2 (Sample Rate): 0: Invalid and ignored 1/2/3/4/5/6/7 = 1/10/25/50/100/200/400 Hz • Bits 4-5 (Measurement Range[9]): 0/1/2/3 = ±2/±4/±8/±16 *g* • Bits 3, 6, 7: Ignored	• Sample Rate = 10 Hz • Measurement Range = ±8 *g* **0x22**	*accelerometer_sensitivity {* *sample_rate: <value>, (unsigned/Hz)* *measurement_range: <value> (unsigned/g)* *}*
0x42	Acceleration Alarm Threshold Count	2 B	• Number of acceleration events before an acceleration alarm is raised • Acceptable values: ≥ 1 • 0: Invalid and ignored	1 event **0x00 01**	*acceleration_alarm_threshold_count: <value> (unsigned/no unit)*

[9] Measurement ranges ±2 *g*, ±4 *g*, ±8 *g*, ±16 *g* correspond to typical transducer output precisions of 16 m*g*, 32 m*g*, 64 m*g*, 192 m*g*, respectively. Note that if the threshold configured in register 0x44 is equal to or greater than the configured measurement full-scale (2 *g*, 4 *g*, 8 *g*, 16 *g*), then no acceleration event will ever be registered.

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x43	Acceleration Alarm Threshold Period	2 B	• Period in sec over which acceleration events are counted for threshold detection • Acceptable values: ≥ 5 • 0-4: Invalid and ignored	10 seconds **0x00 0A**	*acceleration_alarm_threshold_period: <value> (unsigned/sec)*
0x44	Acceleration Alarm Threshold	2 B	• Unsigned, 1 milli-g/LSB	800 mg **0x03 20**	*acceleration_alarm_threshold: <value> (unsigned/g)*
0x45	Acceleration Alarm Grace Period	2 B	• Time in sec to pass after the last acceleration alarm before the next alarm can be registered • Acceptable values: ≥ 15 • 0-14: Invalid and ignored	5 min **0x01 2C**	*acceleration_alarm_grace_period: <value> (unsigned/sec)*
0x46	Acceleration Alarm Enabled	1 B	• Bit 0: 0/1 = Acceleration alarm disabled/enabled • Bits 1-7: Ignored	Alarm Enabled **0x01**	*acceleration_alarm_enabled: <value> (unsigned/no unit)*

3.2.5.1 Mode

The accelerometer can be enabled or put in a power-down mode to save battery life. Additionally, it is possible to enable/disable X, Y, Z axes independently. When an axis is disabled, it is not considered in monitoring acceleration events. Also, its corresponding value in the output acceleration vector is 0.

The *Mode* register also controls, via the Accelerometer Assist bit, whether a registered acceleration event or acceleration clear triggers a transition to the GNSS SEARCH state, as explained above.

NOTE: If the accelerometer is disabled, no periodic or event-based reports related to the accelerometer are produced.

3.2.5.2 Sensitivity

When enabled (powered on), the accelerometer always samples the transducer element at a fixed rate, called the *Sample Rate*. To capture an acceleration event, the physical event needs to last longer than the sample period. Larger sample rates have a shorter period and can therefore resolve shorter acceleration events. However, sampling the transducer at a larger rate increases the power usage, impacting the battery life. Table 3-9 shows typical current draw deltas (with respect to the background current at sleep) for the different sample rates when the accelerometer is enabled.

Table 3-9: Typical Current Draw Deltas at 3.6 V for Different Accelerometer Sample Rates

Sample Rate [Hz]	1	10	25	50	100	200	400
Current Draw [μA]	1.0	1.5	2.3	3.7	6.1	11.4	22.0

Furthermore, the Sensitivity register sets the measurement range or full-scale, which shows the dynamic range of accelerations that can be monitored on any enabled axis. Note that when enabled, the accelerometer is always put in a low-power mode, which means the output acceleration values on any given axis (X, Y, or Z), is an 8-bit signed number. Therefore, a measurement range of ±2 g implies a precision of 4/256 g/LSB.

3.2.5.3 Acceleration Alarm Threshold Count

By default, the accelerometer raises an acceleration alarm each time it detects movement. Depending on the use case, it may be desirable to increase the threshold count to reduce sensitivity. This feature is to allow for filtering out short acceleration events, while still allowing longer acceleration events to be reported.

3.2.5.4 Acceleration Alarm Threshold Period

The Acceleration Alarm Threshold Period is the amount of time that acceleration events are accumulated for threshold detection. For example, an Acceleration Alarm Threshold Period of 10 s accumulates acceleration events over a 10 s period from the time of first detection. An acceleration event is registered only if the Acceleration Alarm Threshold Count is reached before the time expires.

3.2.5.5 Acceleration Alarm Threshold

This parameter is the g-threshold for an acceleration alarm event. Acceleration alarm events are registered only if the Acceleration Alarm Threshold is exceeded on at least one of the enabled axes (X, Y, Z) within the Acceleration Alarm Threshold Period for at least the Acceleration Alarm Threshold Count number of times.

3.2.5.6 Acceleration Alarm Grace Period

The *Grace Period* determines how long the Tracker waits before the previously registered acceleration event is considered clear. For example, a grace period of 5 min results in the Tracker registering an acceleration clear 5 min after the last registered event.

3.2.5.7 Acceleration Alarm Enabled

The accelerometer event-based reporting is disabled or enabled through this register. If disabled, no acceleration alarm or alarm clear is reported OTA.

3.2.5.8 Accelerometer Configuration DL Examples

- Read current value of *Acceleration Alarm Threshold*:
    - DL payload: { 0x 44 }
        - Reg 44 with the write bit set to false
- Disable Accelerometer Assist feature:
    - DL payload: { 0x C0 87 }
        - Reg 40 with its write bit set to true
        - Bit 6 set to 0
        - All other bits set to default

3.2.6 BLE Configuration

The BLE module is embedded in the MCU. It plays the role of a BLE central device that can search to discover nearby BLE peripherals periodically or on-demand. It can be used as a standalone proximity sensor used for positioning.

Figure 1-2 shows how periodic BLE scans are performed; also see Section 1.2 for how BLE operates in the ORCA. Table 3-10 shows the list of BLE configuration registers. In this table, the bit indexing scheme is as shown in Figure 3-2. All the registers have R/W access.

Table 3-10: BLE Configuration Registers

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x50	Mode	1 B	• Bits 0-6: ***N*** Number of reported devices (1–127) 0: Disables BLE • Bit 7: ***R*** 0/1 = Repetition mode disabled/enabled	• Up to 8 devices reported (***N*** = 8) • Repetition mode disabled (***R*** = 0) **0x08**	*ble_mode: {* *num_reported_devices: <value>, (unsigned/no unit)* *repetition_enabled: <value> (unsigned/no unit)* *}*

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x51	Scan Duration	2 B	• Bits 8-15: Scan duration for event-based reports (1 sec/LSb) Acceptable values: 1, 2, …, 255 0: Invalid and ignored • Bits 0-7: Scan duration for periodic reports (1 sec/LSb) Acceptable values: 1, 2, …, 255 0: Invalid and ignored	• Periodic Scan Duration = 3 s • Event-Based Scan Duration = 1 s **0x01 03**	*ble_scan_duration: {* *event_based: <value>, (unsigned/sec)* *periodic: <value> (unsigned/sec)* *}*
0x52	Scan Interval	2 B	• Scan interval (1 ms/LSb) • Acceptable values: 3, …, 10000 • Other values: Invalid and ignored	30 ms **0x00 1E**	*ble_scan_interval: <value> (unsigned/sec)*
0x53	Scan Window	2 B	• Scan window (1 ms/LSb) • Acceptable values: 3, …, "Scan Interval" • Other values: Invalid and ignored	30 ms **0x00 1E**	*ble_scan_window: <value> (unsigned/sec)*
0x54	BD_ADDR Range 0	9 B	• Range 0 for filtered BD_ADDRs • $B_0:B_1:B_2:B_3:B_4:B_5$ to $B_0:B_1:B_2:B_6:B_7:B_8$ • OUI = $B_0:B_1:B_2$ • $LAP_{start} = B_3:B_4:B_5$ • $LAP_{end} = B_6:B_7:B_8$	Filter Range 0 disabled **0x00 00 00 00 00 00 00 00 00**	*bd_addr_range0: {* *oui: <value>, (unsigned/no unit)* *lap_start: <value>, (unsigned/no unit)* *lap_end: <value> (unsigned/no unit)* *}*

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x55	BD_ADDR Range 1	9 B	• Range 1 for filtered BD_ADDRs • $B_0:B_1:B_2:B_3:B_4:B_5$ to $B_0:B_1:B_2:B_6:B_7:B_8$ • OUI = $B_0:B_1:B_2$ • $LAP_{start} = B_3:B_4:B_5$ • $LAP_{end} = B_6:B_7:B_8$	Filter Range 1 disabled **0x00 00 00 00 00 00 00 00 00**	*bd_addr_range1: {* *oui: <value>,* *(unsigned/no unit)* *lap_start: <value>,* *(unsigned/no unit)* *lap_end: <value>* *(unsigned/no unit)* *}*
0x56	BD_ADDR Range 2	9 B	• Range 2 for filtered BD_ADDRs • $B_0:B_1:B_2:B_3:B_4:B_5$ to $B_0:B_1:B_2:B_6:B_7:B_8$ • OUI = $B_0:B_1:B_2$ • $LAP_{start} = B_3:B_4:B_5$ • $LAP_{end} = B_6:B_7:B_8$	Filter Range 2 disabled **0x00 00 00 00 00 00 00 00 00**	*bd_addr_range2: {* *oui: <value>,* *(unsigned/no unit)* *lap_start: <value>,* *(unsigned/no unit)* *lap_end: <value>* *(unsigned/no unit)* *}*
0x57	BD_ADDR Range 3	9 B	• Range 3 for filtered BD_ADDRs • $B_0:B_1:B_2:B_3:B_4:B_5$ to $B_0:B_1:B_2:B_6:B_7:B_8$ • OUI = $B_0:B_1:B_2$ • $LAP_{start} = B_3:B_4:B_5$ • $LAP_{end} = B_6:B_7:B_8$	Filter Range 3 disabled **0x00 00 00 00 00 00 00 00 00**	*bd_addr_range3: {* *oui: <value>,* *(unsigned/no unit)* *lap_start: <value>,* *(unsigned/no unit)* *lap_end: <value>* *(unsigned/no unit)* *}*

NOTE: If BLE is disabled through register 0x50, no periodic or event-based report related to BLE is produced.

3.2.6.1 Mode

The *Mode* register controls both:

- ***N:*** the number of reported devices (MAC address + RSSI value pairs) to be reported in an UL following a BLE scan, and
- ***R:*** enabling or disabling repetition mode.

As explained in Section 1.2, it is possible to observe more than 1 advertisement from a peripheral BLE device during a single Tracker scan duration. The repetition mode bit of reg 0x50 controls whether multiple instances of observed device advertisements are reported or only 1 report per device.

A. **Normal Mode (Default), *R* = 0:** Only a single MAC address + RSSI value pair is reported for each discovered device. The value reported for each device is from the last observed advertisement of that device that was observed during the Tracker’s scan.

B. **Repetition Mode, *R* = 1:** Multiple MAC address + RSSI value pairs can be reported for each discovered device, if observed. The values reported are the last ***N*** observed advertisements during the Tracker’s scan, regardless of which BLE devices they are from.

Reg 0x50 also controls whether BLE scanning is disabled entirely.

3.2.6.1 Scan Duration, Interval, and Window.

Figure 1-2 shows the BLE scan scheme in the Tracker when the BLE scan is enabled. As shown in the figure, BLE scans are performed periodically with a configurable scan period. Also, each scan duration is divided into scan intervals. The BLE scan is performed only in a scan window portion of the scan interval. The ratio of the scan window to the scan interval is the scan duty cycle. 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.

As observed from Table 3-10, the scan duration can be independently set for periodic reports and event-based reports through register 0x51. A BLE event-based scan and report is made after a magnet event if such events are configured to trigger a BLE scan (see Section 3.2.3). Other BLE scan configuration parameters, i.e. number of reported devices, scan interval, and scan window, remain the same for both periodic and event-based scans.

3.2.6.2 Filtering

As explained in Section 1.2, there are two types of BLE scan reporting: *Basic* and *Filtered*.

With basic reporting, (up to) ***N*** devices (MAC address + RSSI value pairs) are reported.

With filtered reporting, (up to) ***N*** devices (MAC address + RSSI value pairs) with BD_ADDRs (Bluetooth Device MAC Addresses) within one of configured BD_ADDR ranges are reported. Up to 4 BD_ADDR ranges can be defined through registers 0x54 to 0x57. Each BD_ADDR range register has 9 bytes: B_0 (MSB) to B_8 (LSB).

A BD_ADDR consists of an *Organizationally-Unique Identifier* (OUI) comprising the 3 MSBs, followed by a *Lower Address Part* (LAP) comprising the 3 LSBs. Each BD_ADDR range is a 9-byte OUI:LAP_{start}-LAP_{end} that determines the range of BD_ADDRs as OUI:LAP_{start} to OUI:LAP_{end}. Therefore, OUI is the same and known for all devices in each range.

For example, if the only discoverable BLE devices of interest all have MAC addresses that begin with AC233F (OUI) and only the last 3 bytes are different for each device (LAPs), the BD_ADDR range to filter for only these devices would be AC233F:000000-FFFFFF. In other words, this BD_ADDR range means that the Tracker will filter the discovered devices to include only those with MAC addresses from AC233F000000 to AC233FFFFFFF, inclusive.

With filtered reporting, after a scan is complete, the list of the discovered devices is first filtered to include only those lying in one of the ranges defined in registers 0x54 to 0x57. Then, (up to) ***N*** devices in the filtered list are reported using the format described in Section 2.3. Devices falling under each range are reported in one or more messages with a range specific header: 0xB0 for Range 0, 0xB1 for Range 1, 0xB2 for Range 2, and 0xB3 for Range 3. Only LAPs of the devices followed by their RSSIs are reported in the filtered message, as the first 3 bytes are implicitly known.

The following rules apply to the operation of the 4 BD_ADDR ranges:

1. A range set to all 0's: An **inactive range**. Otherwise: an **active range**.

2. All 4 ranges inactive: Basic reporting is enabled (the reporting is be performed with message type header 0x0A as per Section 2.2). Otherwise, filtered reporting is enabled.

3. With filtered reporting, in every round of BLE scanning, there will be reports corresponding to each active range. If no devices are found to be reported for an active range, an empty list with the header corresponding to that active range is reported (i.e. 0xB0, 0xB1, 0xB2, or 0xB3). For example, if only register 0x54 is non-zero, only Range 0 is active, thus, discovered devices are reported in messages with header 0xB0, and if no device is found under Range 0, a one-byte message of 0xB0 is reported. If only registers 0x54 and 0x55 are non-zero, then only Range 0 and Range 1 are active, and discovered devices are reported in messages with header 0xB0 for Range 0 and header 0xB1 for Range 1. In this case, in every BLE scan, we will ALWAYS have reports (of even an empty list) with both headers 0xB0 and 0xB1.

4. A range with $LAP_{start} > LAP_{end}$: The range is active, but empty (i.e. always an empty list is reported with its corresponding header—0xB0, 0xB1, 0xB2, or 0xB3).

5. An active range with $LAP_{start} = LAP_{end}$: The range has only one BD_ADDR in it.

6. It is possible that the ranges overlap. A beacon that is in at least one of the ranges and is to be reported, is always reported under the first range (from Range 0 to 3) that it falls into.

3.2.6.3 BLE Configuration DL Examples

- Configure the Tracker to report the nearest (strongest) beacon only:
    - DL payload: 0xD0 01
- Decrease the scan duty cycle to 50% while keeping scan durations the same to save battery life:
    - DL payload: 0xD3 00 0F
- Set filters to only report devices with MAC addresses ABCDEF000001 and ABCDEF500000 – ABCDEF999999:
    - DL payload: 0xD4 AB CD EF 00 00 01 00 00 01 D5 AB CD EF 50 00 00 99 99 99

3.2.6.4 Guidelines on BLE Scan Configuration

In the case of periodic BLE scanning, although the BLE scan period, scan duration, and number of devices to report can be freely configured to different values, a bad combination 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 sec.

Table 3-11 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 the filtered reporting mode where 4 bytes is needed per device. For example, from Table 3-11, 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 3-11: 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
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.

3.2.7 Temperature Threshold Configuration

The Tracker supports threshold transmission on the temperature. The temperature is measured from the MCU.

When the temperature thresholds are enabled, the Tracker reports the temperature when it leaves the configured threshold window, and once again when the temperature re-enters the threshold window.[10]

The Threshold mode is compatible with periodic reporting of the temperature; both can be disabled or enabled independently.

Table 3-12 shows a list of configuration registers for the temperature threshold setting. In this table, the bit indexing scheme is as shown in Figure 3-2. All the registers have R/W access.

Table 3-12: Temperature Threshold Configuration Registers

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x60	Sample Period in Idle State	4 B	• Sample period of temperature in sec in Idle state • Acceptable values: 10, 11, 86400	300 s **0x00 00 01 2C**	*temperature_sample _period_idle: <value> (unsigned/sec)*

[10] The threshold window is defined as the open interval "(Low Threshold, High Threshold)"; i.e., even if the temperature is equal to Low Threshold or High Threshold, the Tracker is considered to have left the threshold window.

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
			• Other values: Invalid and ignored		
0x61	Sample Period in Active State	4 B	• Sample period of temperature in sec in Active state • Acceptable values: 10, 11, 86400 • Other values: Invalid and ignored	60 s **0x00 00 00 3C**	*temperature_sample_period_active: <value> (unsigned/sec)*
0x62	High/Low Thresholds	2 B	• Bits 8-15: High temperature threshold (signed, 1°C/LSb) • Bits 0-7: Low temperature threshold (signed, 1°C/LSb)	• High threshold = 30°C • Low threshold = 15°C **0x1E 0F**	*temperature_thresholds { high: <value>, (signed/°C) low: <value> (signed/°C) }*
0x63	Thresholds Enabled	1 B	• Bit 0: 0/1 = Thresholds disabled/enabled • Bits 1-7: Ignored	Disabled **0x00**	*temperature_thresholds_enabled: <value> (unsigned/no unit)*

3.2.7.1 Sample Period in Idle/Active State

The Idle/Active sample period determines how often the temperature is checked when the reported value is inside/outside the threshold window. When first enabled, the temperature transducer starts in the Idle state.

3.2.7.2 High/Low Threshold

Temperature thresholds are stored in a single 2-byte register, with the upper byte storing the “high” temperature threshold, and the lower byte storing the “low” temperature threshold with a 1°C per bit precision. Each temperature threshold is stored/transmitted as a 1-byte 2-s complement number. The “high” temperature threshold must be greater than the “low” temperature threshold.

3.2.7.3 Thresholds Enabled

The Thresholds Enabled register enables and disables the threshold reporting on the temperature. The thresholds and sample periods can be configured but are not activated unless the Thresholds Enabled bit is set.

3.2.7.4 Example DL Messages

- Set Temperature Thresholds:
  - DL payload: { 0x E2 23 F6 }
    - Reg 62 with write bit set to true
    - High threshold set to 35°C
    - Low threshold set to -10°C
- Read Sample Periods:
  - DL payload: { 0x 60 61 }
    - Reg 60 and Reg 61 with their write bits set to false

3.2.8 Command and Control

The *Command and Control* registers are used are used to save settings, restart the device OTA, read the application and LoRaMAC versions, and reset the configuration settings to default.

Table 3-13 shows the structure of the Command and Control registers. In this table, the bit indexing scheme is as shown in Figure 3-2.

Table 3-13: Command and Control Register

Address	Access	Name	Size	Description	JSON Variable (Type/Unit)
0x70	W	Flash Write Command	2 B	• Bit 13: 0/1 = Do not write/Write App Configuration • Bit 14: 0/1 = Do not write/Write LoRaMAC Configuration • Bit 0: 0/1 = Do not restart/Restart Tracker • 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	JSON Variable (Type/Unit)
0x71	R	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 (see Section 3.2.8.1)	*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)* *}*
0x72	W	Reset to Factory Defaults[11]	1 B	• 0x0A = Reset App Configuration • 0xB0 = Reset LoRaMAC Configuration • 0xBA = 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)* *}*

Note: The Command and Control Registers 0x70 and 0x71 are always executed after the full DL configuration message has been decoded. The reset command should always be sent as an unconfirmed DL message. Failure to do so may cause a poorly designed NS to continually reboot the Tracker.

[11] After sending the reset-to-factory-defaults command, the Sensor is automatically reset with corresponding default configuration values.

3.2.8.1 Flash Write Command

Configuration changes are not retained after a power cycle unless they are saved in the flash memory. The *Flash Write Command* register should be written to in order to save changes that have been written to other registers. This can be done in a separate DL at any time, or be included in the same payload as the other write commands.

Changes made to the LoRaMAC registers (0x10 to 0x15) must have bit 14 in the command set to 1 in order to be saved. Changes made to the application registers (0x20 to 0x63) must have bit 13 set to 1 in order to be saved. These bits can be set to any combination of 1s and 0s.

The *Flash Write Command* register can also be used to reset the device and cause it to rejoin the network. This is done by setting bit 0 to 1. Immediately after receiving this command in a DL, the Tracker will reset. This means that if the command was sent in a confirmed DL, the confirmation reply UL will not be sent. The Tracker will rejoin the network but then get the command sent again, causing a loop of continual rebooting. It is important to not send the reset command as a confirmed DL.

3.2.8.2 Metadata

Bits 32 to 55 of the *Metadata* register contain the application revision numbers which define the FW version. The FW version is reported in the format as shown in Figure 3-3, which is shown using the example FW v1.0.15.

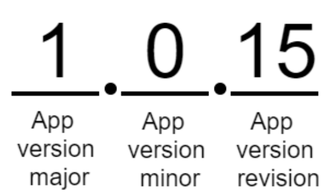


Figure 3-3: Example FW version format

Bits 8-31 in the *Metadata* register contain the LoRaMAC version numbers. The format is the same as shown in Figure 3-3. 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 LoRaMAC region number is the last byte of the *Metadata* register. Current LoRaMAC regions and corresponding region numbers for the Tracker are listed in Table 3-14.

Table 3-14: LoRaMAC Regions and Region Numbers

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

3.2.8.3 Reset to Factory Defaults

The *Reset Configuration to Factory Defaults* register is written to in order to reset all of the other register values (0x10 to 0x63).

3.2.8.4 Command and Control Examples

- Write Application Configuration to flash
  - DL payload: 0xF0 20 00
- Write Application and LoRaMAC Configurations to flash
  - DL payload: 0xF0 60 00
- Reboot Device
  - DL payload: 0xF0 00 01
- Get FW version, and reset App Configuration to factory defaults
  - DL payload: 0x71 F2 0A

4 Appendix A: Default Values

Table 4-1: Default Values of Configuration Registers

Register Name	Code Name	Reg. Address (Hex)	Default Value (Hex)	Section
LoRaMAC Join Mode		10	80	LoRaMAC Configuration
LoRaMAC Options		11	00 0E	
LoRaMAC DR and Tx Power		12	00 00	
LoRaMAC Rx2 Window (EU868)		13	33 D3 E6 08 00	
LoRaMAC Rx2 Window (US915)		13	37 08 70 A0 08	
LoRaMAC Rx2 Window (AS923)		13	37 06 EA 00 02	
LoRaMAC Rx2 Window (AU915)		13	37 08 70 A0 08	
LoRaMAC Rx2 Window (IN865)		13	33 A6 80 F0 02	
LoRaMAC Rx2 Window (KR920)		13	36 F3 13 E0 00	
LoRaMAC Rx2 Window (RU864)		13	33 CD 69 E0 00	
Seconds per Core Tick	MEASUREMENT_PERIOD	20	00 00 0E 10	Periodic Tx Configuration
Ticks per Battery	BATTERY_TICKS_PER_PERIOD	21	00 18	
Ticks per GNSS in STILLNESS State	GNSS_STILLNESS_TICKS_PER_PERIOD	22	00 01	
Ticks per GNSS in MOBILITY State	GNSS_MOBILITY_TICKS_PER_PERIOD	23	00 01	
Ticks per Accelerometer	ACCEL_TICKS_PER_PERIOD	24	00 00	
Ticks per BLE in DEFAULT State	BLE_DEFAULT_TICKS_PER_PERIOD	25	00 06	
Ticks per BLE in STILLNESS State	BLE_STILLNESS_TICKS_PER_PERIOD	26	00 06	
Ticks per BLE in MOBILITY State	BLE_MOBILITY_TICKS_PER_PERIOD	27	00 06	
Ticks per Temperature	MCU_TEMP_TICKS_PER_PERIOD	28	00 00	
Ticks per FSM State	FSM_STATE_TICKS_PER_PERIOD	29	00 00	
Reed Switch Mode		2A	20	Magnetic Reed Switch Configuration
GNSS Mode		30	80	GNSS Configuration
GNSS Ground Speed Thresholds		31	1E 0A	
GNSS Value to Tx		33	03	

Register Name	Code Name	Reg. Address (Hex)	Default Value (Hex)	Section
Geofence 0/1/2/3 Definition		34/35/36/37	00 00 00 00 00 00 00 00	
Accelerometer Mode		40	C7	Accelerometer Configuration
Accelerometer Sensitivity		41	22	
Acceleration Alarm Threshold Count		42	00 01	
Acceleration Alarm Threshold Period		43	00 0A	
Acceleration Alarm Threshold		44	03 20	
Acceleration Alarm Grace Period		45	01 2C	
Acceleration Alarm Enabled		46	01	
BLE Mode		50	08	BLE Configuration
BLE Scan Duration	BLE_SCAN_DURATION	51	01 03	
BLE Scan Interval	BLE_SCAN_INTERVAL	52	00 1E	
BLE Scan window	BLE_SCAN_WINDOW	53	00 1E	
BD_ADDR Range 0/1/2/3		54/55/56/57	00 00 00 00 00 00 00 00 00	
Temperature Sample Period in Idle State		60	00 00 01 2C	Temperature Threshold Configuration
Temperature Sample Period in Active State		61	00 00 00 3C	
Temperature High/Low Thresholds		62	1E 0F	
Temperature Thresholds Enabled		63	00	

References

[1] LoRa Alliance, "LoRaWAN Regional Parameters," ver. 1.0.2, rev. B, Feb 2017.

[2] TEKTELIC Communications Inc., "Industrial GPS Asset Tracker UL/DL Decoding/Encoding Tool," ver 0.1, Apr 2020.

[3] LoRa Alliance, "LoRaWAN Regional Parameters," ver. 1.0.2, rev. B, Feb 2017.

[4] LoRa Alliance, "LoRaWAN Specification," ver. 1.0.2, rev. B, Jul 2016.

[5] TEKTELIC Communications, Inc., "Sensor Configuration Tool," TEKTELIC Communications, Inc., June 2021. [Online]. Available: http://sensor-config.tektelic-dev.com/. [Accessed 28 June 2021].

[6] Bluetooth SIG, "Core Specification 5.0," 6 Dec 2016. [Online]. Available: https://www.bluetooth.com/specifications/specs/core-specification-5/. [Accessed 15 November 2021].