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ORCA

Industrial GPS Asset Tracker

Technical Reference Manual

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Revision History

TRM Version	Date	Editor	FW Version	Comments

0.1	August 13, 2019	Reza Nikjah	0.1.0	• 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 ULs
				  ○ 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.

0.2	October 15, 2019	Conor Karperien	0.1.0	Changed formatting to reflect design updates

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 0x 00 to 0x 05 (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 0x 40 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 0x 29 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 0x 44. • Updated List of Acronyms. • Updated BLE Section 1.2 for clarity. • Changed "whitelisting" terminology to "filtered reporting." • Corrected LED pattern descriptions in Section 1.6. • Updated BLE UL format Section 2.3 for clarity. • Updated response to configuration and control commands description in Section 2.5 for clarity. • Updated Accelerometer Configuration description Section 3.2.6 for clarity. • Added missing subsections in Section 0. • Minor formatting changes.
0.12	May 27, 2022	Carter Mudryk	0.3.54	Corrected and clarified Geofence Status reporting description in §3.2.5.5.

TRM Version	Date	Editor	FW Version	Comments
0.13	May 29, 2022	Carter Mudryk	0.3.54	• Minor grammatical corrections. • Corrected default value of register 0x 30 in Table 3-6. • Corrected failed POST LED pattern in Section 1.6.1. • Moved FW versioning notes to Revision History table. • Updated product name terminology to “ORCA.”
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.
1.0	September 18, 2023	Carter Mudryk	1.0.0	• Created register 0x 32 to control GNSS Diagnostics Value to Tx report options. • Added subsection to describe register 0x 32 functions. • Added port 16 GNSS diagnostic reporting functional description and updated other relevant sections. • Renamed register 0x 33 to “GNSS Data Value to Tx.” • Redefined register 0x 33 JSON variable as *gnss_data_tx.* • Added new GNSS diagnostic UL packet formats to Table 2-2. • Updated list of acronyms. • Changed default values for Ticks per BLE Report for STILLNESS/MOBILITY/DEFAULT states. • Updated table of default configuration values in the Appendix. • Added GNSS and accelerometer operation description sections. • Updated FSM description and diagram with respect to accelerometer assist. • Added magnet site and LED location figures. • Corrected some LED pattern descriptions. • Added examples sections that were missing. • Changed the ground speed threshold info to reflect the fact that only one threshold is used by SW. • Minor grammatical and formatting changes.

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List of Acronyms

2-D 2-Dimensional
ABP .... Activation By Personalization
Accl .... Acceleration/Accelerometer
ADR .... Adaptive Data Rate
App .... Application
AS .... Asia
AU .... AUstralia
BD_ADDR .... Bluetooth Device ADDRess
BLE .... Bluetooth Low Energy
BLET .... BLE Tracker
C .... Count
CN .... ChiNa
CRC .... Cyclic Redundancy Check
D .... Default/Disabled
DL .... DownLink
DR .... Data Rate
EIRP .... Effective Isotropic Radiated Power
EoS .... End of Service
EU .... EUrope
FSM .... Finite State Machine
FW .... FirmWare
GLONASS .... GLObal NAvigation Satellite System
GNSS ... . Global Navigation Satellite Systems
gp .... grace period
GPS .... Global Positioning System
HW .... HardWare
ID .... IDentity / IDentifier
IN .... INdia
IoT .... Internet of Things
IP .... Ingress Protection
JSON .... JavaScript Object Notation
KR .... KoRea
LAP .... Lower Address Part
LED .... Light-Emitting Diode
LoRa .... Long-Range
LoRaMAC .... LoRaWAN MAC
LoRaWAN .... LoRa Wide Area Network
LoS .... Line-of-Sight
LSb .... Least Significant bit
LSB .... Least Significant Byte
LTC .... Lithium Thionyl Chloride
M .... MOBILITY
MAC .... Medium Access Control
MCU .... MicroController Unit
MSb .... Most Significant bit
MSB .... Most Significant Byte
NA .... North America
NE .... NorthEast
NS .... Network Server
OTA .... Over-The-Air
OTAA ... . OTA Activation
OUI .... Organizationally Unique Identifier
PCBA .... Printed Circuit Board Assembly
POST .... Power-On Self-Test
QZSS .... Quasi-Zenith Satellite System
R/W .... Read/Write
RF .... Radio Frequency
RFU .... Reserved for Future Use
RO .... Read Only
RSSI .... Received Signal Strength Indicator
RU .... RUssia
Rx .... Receive / Receiver
S .... STILLNESS
SBAS .... Satellite-Based Augmentation System
SNR .... Signal-to-Noise Ratio
SW .... SoftWare
th .... threshold
TRM .... Technical Reference Manual
TTF .... Time-To-Fix
Tx .... Transmit / Transmitter
UL .... UpLink
UTC .... Coordinated Universal Time
v .... 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 §3.2.9.2.

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 ORCA is a GNSS-capable LoRaWAN IoT sensor run on LTC batteries and packed into a rugged IP67 casing. The GNSS receiver supports receiving GPS, GLONASS, Galileo, BeiDou, QZSS, and SBAS signals, and past location data can be retrieved from the flash log. The ORCA's main use-case is monitoring and reporting geolocation in industrial environments in different parts of the world.

The ORCA also supports BLE and is capable of scanning for and reporting nearby BLE devices (up to the LoS range of approximately 50 m). This data may then be passed to a location-resolving application to provide indoor location information.

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

Changes between STILLNESS and MOBILITY states of the ORCA help optimize power usage by reporting the GNSS fixes at user-configurable rates, depending on how often a location report is required. The ORCA determines its state based entirely on the GNSS-derived ground speed, which is obtained in every successful GNSS search.

Additional sensing functions on the ORCA include on-board MCU temperature and battery voltage. The ORCA has an estimated battery lifetime of 5 years.[1]

[1] Based on total battery capacity and default configuration settings at room temperature.

Table 1-1 presents the currently available ORCA HW variant. The phrase "2x D-Cell" in this model refers to having 2 battery cradles to receive up to 2 D-cell LTC batteries. Table 1-2 lists the ORCA variants for the different LoRaWAN RF regions. Refer to the LoRaWAN Specifications for a list of these regions and the LoRaWAN Regional Parameters for the Tx and Rx bands in each LoRaWAN region [1] [2]. As shown in Table 1-2, the different RF variants use the same HW but are distinguished through different regional 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 ORCA 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 (ORCA to NS)	Real-time sensor data from the MCU, GNSS receiver, battery gauges, and accelerometer	**10**
	Return logged (historical) GNSS time and position	**15**
	Real-time GNSS diagnostic information	**16**
	Discovered BLE devices	**25**
	Response to Configuration and Control Commands	**100**
DL (NS to ORCA)	Request GNSS logged (historical) time and position	**15**
	Configuration and Control R/W 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)
		Every time the accelerometer grace period elapses (when motion stops)
Acceleration alarm	Event-Based	Every time the accelerometer threshold is breached (when motion begins)
		Every time the accelerometer grace period elapses (when motion stops)
Discovered BLE devices (up to 8) when in STILLNESS or MOBILITY	Periodic	Disabled
Discovered BLE devices (up to 8) when in DEFAULT	Periodic	1 hour
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 online tool ATLAS for a thorough tool to decode any UL frame payload, as well as encode any DL frame payload as described in this document [3].

1.1 Finite State Machine Description

The ORCA has an internal Finite State Machine (FSM), primarily to keep track of whether it is mobile or stationary. Figure 1-1 shows the FSM flow and Table 1-5 lists the glossary and notes. The following states are defined in the FSM:

- **STARTUP**: In this state, the ORCA boots up, conducts POSTs, and performs initializations. Applying the magnetic pattern[2] in any state causes a transition to STARTUP.

- **DEEP SLEEP**: The lowest energy state of the ORCA, DEEP SLEEP is used for shipping. It is possible to transition to this state from any other by pressing the sleep button on the ORCA board (labelled SW2). Applying the magnetic pattern[2] will wake the ORCA up, transitioning into STARTUP.

- **JOIN**: When the ORCA is attempting to join a LoRa network.

- **GNSS SEARCH**: When the ORCA is attempting to acquire GNSS fixes[3]. The results of the search will determine whether it transitions to STILLNESS or MOBILITY.

- **GNSS DISABLED**: The state where the GNSS has been disabled by the user (it is enabled by default). A user-configurable default BLE scanning and reporting period, $T_D^{(BLE)}$, controls how often BLE scans are conducted in this state[4].

- **STILLNESS/MOBILITY**: Ground speed is obtained from GNSS fixes. Following a successful GNSS search, the ground speed is compared to a threshold to determine whether the ORCA is moving (transition to MOBILITY) or stationary (transition to STILLNESS).

  There are 2 user configurable GNSS report periods; one used while in MOBILITY, the other while in STILLNESS. Fix data (and diagnostics, if enabled) are reported with their corresponding periods in these two states.

  If the accelerometer and *Accelerometer Assist* are enabled, a transition to GNSS SEARCH occurs when the accelerometer registers certain types of movement: *Accl Trigger* and

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[2] See §1.5 and §3.2.4 for detailed magnetic behaviour and configuration descriptions.

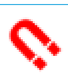
[3] See §1.2 and §3.2.5 for detailed GNSS behaviour and configuration descriptions.

[4] See §1.4 and §3.2.7 for detailed BLE behaviour and configuration descriptions.

Accl Clear[5]. That is, the accelerometer detects the beginning and ending of ORCA movement and triggers additional GNSS scans at these times. These event-based scans provide opportunities for the SW to make STILLNESS↔MOBILITY transitions at the same times the ORCA is physically changing its motion state.

If a GNSS search is unsuccessful (i.e., no satellite fixes could be acquired), a transition to STILLNESS occurs.

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 obtained from GNSS fixes.
S_{th}	0x 31	Ground speed threshold for transitioning between MOBILITY and STILLNESS states.
Accl Assist	0x 40	When enabled, Accelerometer Assist controls whether an Accl Triggers and Accl Clears cause transitions to the GNSS SEARCH state.
Accl Trigger	0x 42 0x 43 0x 44	When threshold-surpassing motion is detected. Specifically, when the filtered (gravity-removed) value of any axis exceeds the acceleration threshold (register 0x 44) at least a certain number of times (register 0x 42) within the threshold period (register 0x 43).
Accl Clear	0x 45	When motion ends and a motion clear report is generated. Specifically, when no additional Accl Triggers are registered for the duration of the grace period timer.
	N/A	Magnetic reset pattern.

[5] See §1.2 and §3.2.6 for detailed accelerometer behaviour and configuration descriptions.

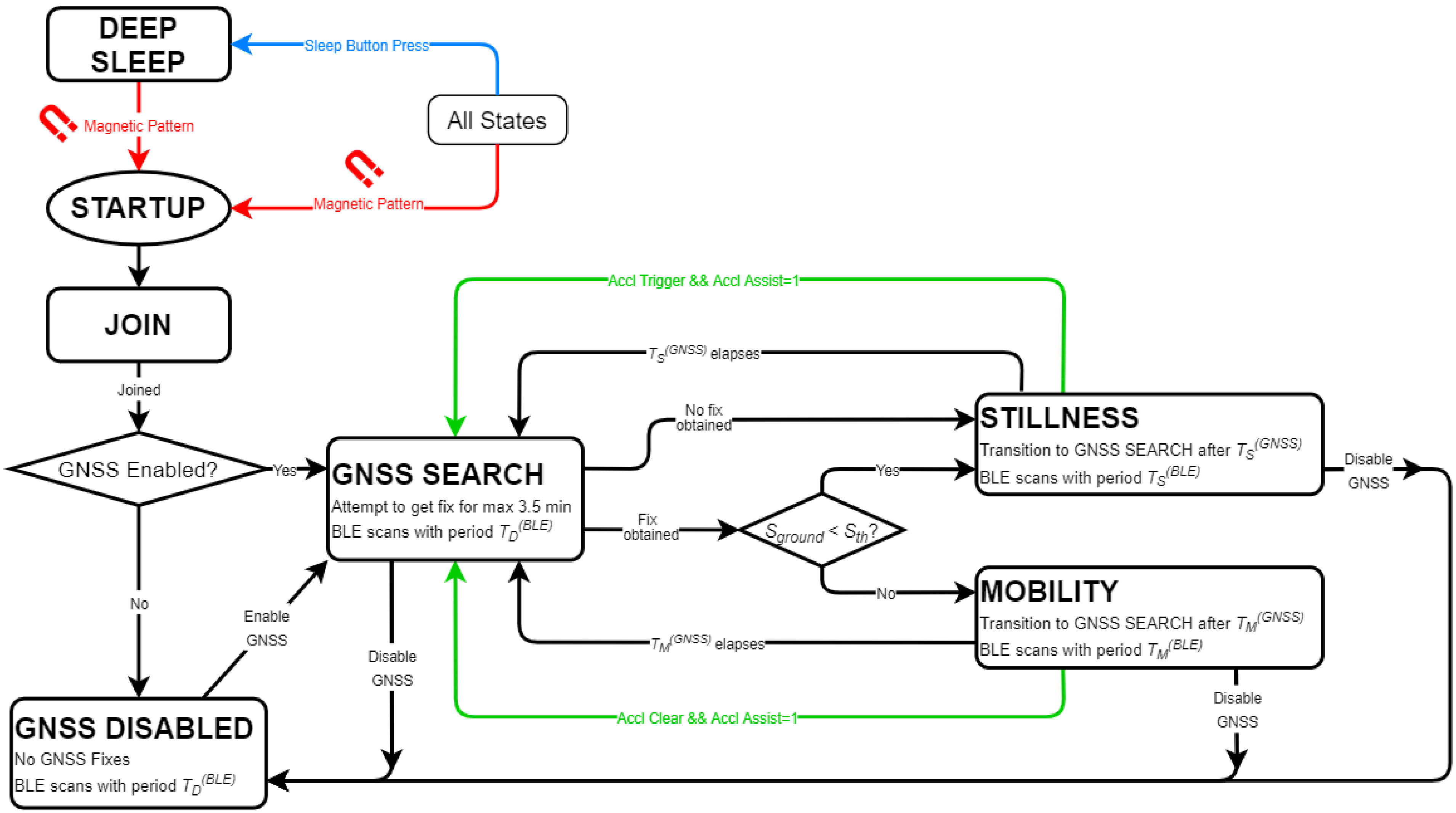


Figure 1-1: The ORCA Finite State Machine

1.2 GNSS Operation

Global Navigation Satellite System (GNSS) is an umbrella term for any system of satellites that provides autonomous geopositioning with global coverage. The GNSSs that ORCA supports are GPS, GLONASS, Galileo, BeiDou, QZSS, and SBAS.

The primary purpose of the GNSS receiver is to conduct GNSS searches, periodically or at interrupt, to obtain geopositioning information. The results from each search are then reported in a LoRaWAN UL.

The ORCA is also equipped with flash storage for logging the historical geopositioning data, which can be retrieved and forwarded through LoRaWAN ULs upon request.

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

1.2.1 Reporting Current GNSS Search Results

GNSS searches are conducted either periodically, upon accelerometer events, or both. Periodic searches are conducted at user-configurable intervals depending on the current motion state of the device[6]. Event-based searches are conducted under certain conditions when Accelerometer Assist is enabled[7].

Once a search begins, it ends as soon as a GNSS fix is obtained. If no fix can be obtained, the search ends after a maximum of 3.5 minutes. It is therefore not recommended that the GNSS reporting periods be set to values less than 3.5 minutes[8].

The results of each search are sent immediately afterwards in a LoRaWAN UL. Which resulting values get sent are user-configurable and are grouped into “data” and “diagnostic” results categories, as shown in Table 1-6. GNSS data are sent on ***LoRaWAN port 10*** and GNSS diagnostics are sent on ***LoRaWAN port 16***. See §3.2.5.3 and §3.2.5.4 for definitions of each of these values.

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[6] See §3.2.3 for reporting period configuration.

[7] See §3.2.6 for detailed Accelerometer Assist operational descriptions.

[8] See §3.2.3.2 for best practices for configuring reporting periods.

Table 1-6: Optional Values for GNSS Reporting

GNSS Data Values	GNSS Diagnostics Values
• UTC* • Position coordinates (latitude, longitude, altitude) * • Ground speed • Geofence statuses	• Number of visible satellites • Average satellite SNR • Fix type • Time-To-Fix (TTF) • Most recent log entry number • Ghost error count

*Enabled to be reported by default.

If the search concludes without being able to obtain a GNSS fix, an "invalid" fix report is sent in place of GNSS data. If any diagnostics values are enabled and available, they are still sent.

Whether configured to be reported or not, the GNSS-derived ground speed is used following every search to determine whether the ORCA should transition to STLLNESS or MOBILITY. This is accomplished using the process described in §1.1.

The ORCA supports setting up to 4 *geofences.* 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 ORCA to send status information about whether it is located inside or outside of a geofence, or if the status is unknown. Each geofence area is a circle and is defined by the latitude and longitude of its center and its radius[9]. By default, all geofences are inactive.

1.2.2 GNSS Log

The ORCA logs GNSS information as time and position fixes are obtained. These fixes can be retrieved later from the flash storage and reported OTA on ***LoRaWAN port 15***. This is useful for scenarios when the ORCA may leave the LoRaWAN coverage area; the data collected during this time can be retrieved once coverage is re-established.

Each log entry contains consists of a pair of corresponding UTC (as the timestamp) and position coordinates from a GNSS fix. Other GNSS data and diagnostics are not logged. The log entries are indexed by *log entry number*, which increments with each new GNSS fix that is logged.

The log entries can be requested either by entering the number of most recent log entries desired, or by entering a UTC desired. See §3.1 for details on the command formats for requesting logged data. See §2.2 for the OTA reporting format of logged data.

[9] See §3.2.5.5 for details about configuring geofences.

1.3 Accelerometer Operation

The accelerometer in the ORCA can be disabled or enabled and supports both periodic-based and event-based reporting. The accelerometer is enabled by default. When enabled, it samples at a configurable rate as a background process throughout all normal operation after joined to the network.

In the case of periodic-based reporting, only the acceleration vector (X-axis, Y-axis, Z-axis) is reported, and includes acceleration due to gravity[6]. This is useful for scenarios where the ORCA orientation is of interest.

In the case of event-based reporting, the high-level function of the accelerometer is used to generate an action(s) when the ORCA begins moving and when it stops moving. The detailed operational flow is shown in Figure 1-3, and the legend for the diagram is shown in Table 1-7.

The accelerometer is "triggered" based on the following criteria:

- ***Accelerometer Trigger***: Registered when a certain number of acceleration samples exceed the trigger threshold within a certain period after the first above-threshold sample is detected. These parameters are all configurable through the registers as described in §3.2.6. Explicitly, with default configuration settings, as soon as the acceleration magnitude on any axis is measured to be greater than 0.8 *g* (register 0x 44, *Acceleration Trigger Threshold*) one time (register 0x 42, *Acceleration Event Threshold Count*) in less than 10 seconds (register 0x 43, *Acceleration Event Threshold Period*), an Accl Trigger is registered.

  With each newly registered Accl Trigger, the *Acceleration Event Grace Period* timer (register 0x 45) is reset and begins counting down again.

Depending on the configuration and current state of the ORCA, an Accl Trigger causes up to 2 types of events for each of the 2 accelerometer functions, as described in the following subsections.

1.3.1 Accelerometer Alarms

Accelerometer Alarms can be enabled or disabled (register 0x 46) and are enabled by default. When enabled, a *motion detected* report is sent OTA when an *Accelerometer Event* is registered. No additional alarm messages are sent until an *Acceleration Clear* is registered, at which time a *motion clear* report is sent.

- ***Accelerometer Event***: A "new" Accl Trigger; an Accl Event is registered upon the first Accl Trigger detected after the previous motion has been considered cleared. That is, if the grace period timer has elapsed and is not currently counting down, an Accl Trigger will start the grace period timer and cause an Accl Event to be registered. If the grace period timer is already counting down, any registered Accl Triggers will not cause additional Accl Event registrations.

- ***Accelerometer Clear***: Registered when the previous Accl Event is considered "cleared." This occurs as soon as no further Accl Triggers are registered for at least a configurable grace period (register 0x 45). That is, after an Accl Event has been registered, the ORCA must not sustain any above-threshold movement during the full 5-minute (default) grace period timer countdown in order for an Accl Clear to be registered. Every time an Accl Trigger is registered after an Accl Event but before the Accl Clear, the grace period timer resets and begins the countdown again.

No alarm ULs are sent on Accl Triggers alone. An example sequence of detected motion and generated acceleration ULs is shown in Figure 1-2.

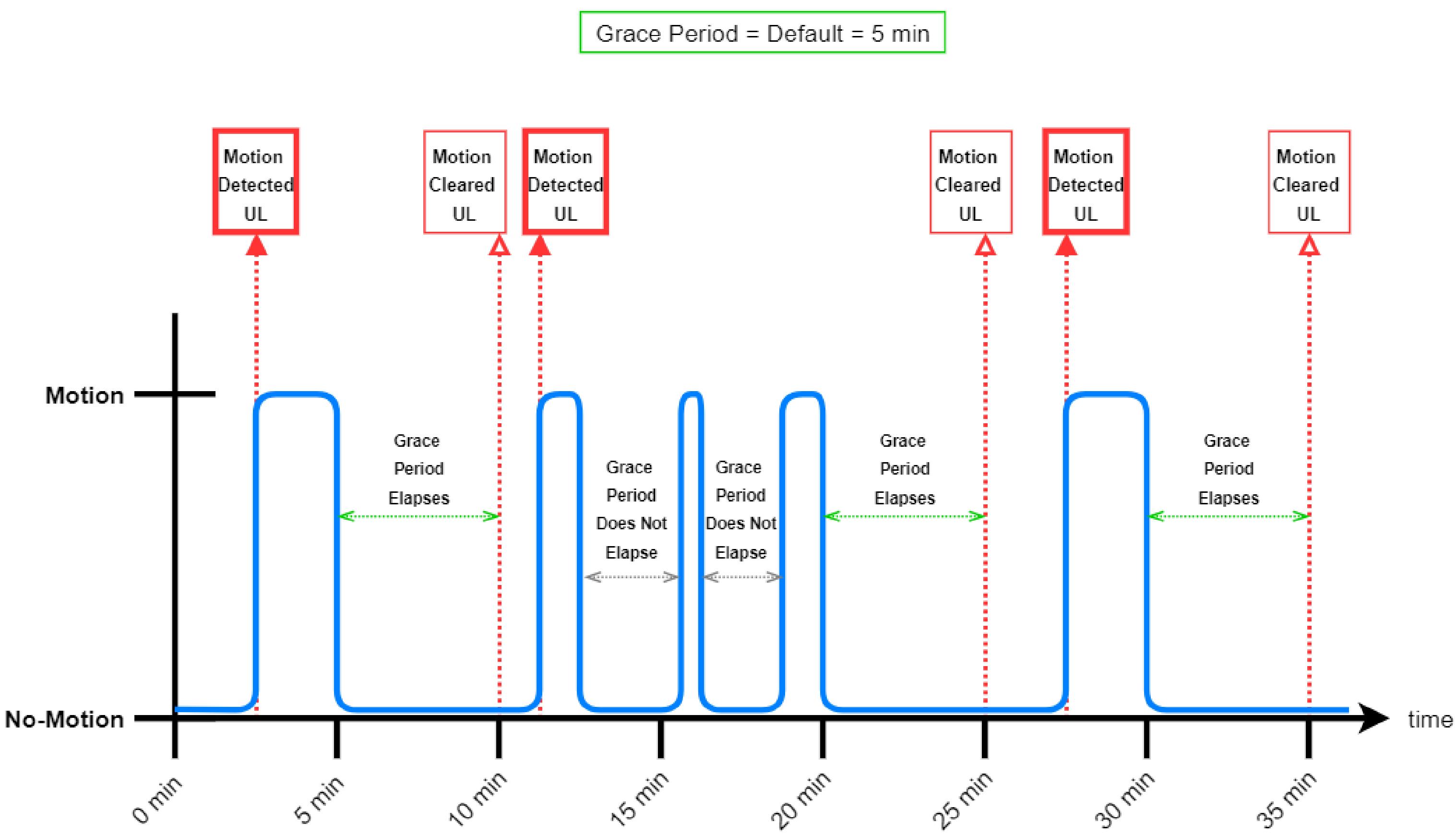


Figure 1-2: Example Sequence of Accelerometer Events and UL Reports

1.3.2 Accelerometer Assist

The *Accelerometer Assist* is a function which, if enabled, allows for a possible STATE transition to GNSS SEARCH when the accelerometer registers Accl Triggers and Accl Clears. That is, the accelerometer detects the beginning and ending of ORCA movement and triggers additional GNSS searches at these times. These event-based scans provide opportunities to make STILLNESS↔MOBILITY transitions in the SW at the same time the ORCA is physically changing its motion state.

The 2 cases where Accl Assist causes actions are:

- When in STILLNESS and an Accl Trigger is registered.
- When in MOBILITY and an Accl Clear is registered.

See Figure 1-3 for the detailed state transition criteria. See Figure 1-1 for the detailed state diagram.

Table 1-7: Legend for the Accelerometer Operational Flow

Symbol	Controlled by Register	Definition
a_{th}	0x 44	The *acceleration trigger threshold* is the absolute acceleration that, if exceeded on any axis for any one sample, increments N_C
N_c	N/A	The number of times an acceleration sample has been above a_{th} since $T_{th}^{(Acc)}$ began counting down.
N_{th}	0x 42	The *acceleration trigger threshold count* is the number of accelerometer samples above a_{th} that must be collected before an Accl Trigger is registered.
$T_{th}^{(Acc)}$	0x 43	The *acceleration trigger threshold period* is the time window during which N_c can increment to possibly be equal to N_{th}, in which case an Accl Trigger is generated. This timer starts when $N_C = 1$.
$T_{gp}^{(Acc)}$	0x 45	The *acceleration event grace period* determines how long the ORCA must be still for before the previously registered acceleration event is considered clear.
Accl Assist	0x 40	When enabled, Accelerometer Assist controls whether an Accl Trigger, Accl Event, and Accl Clear should cause a transition to the GNSS SEARCH state.
Accl Trigger	0x 42 0x 43 0x 44	When threshold-surpassing motion is detected. Specifically, when the filtered (gravity-removed) value of any axis exceeds the acceleration threshold (a_{th}) at least a certain number of times (N_{th}) within the threshold period ($T_{th}^{(Acc)}$). Each Accl Trigger causes the grace period timer ($T_{gp}^{(Acc)}$) to reset and begin elapsing again.
Accl Event	0x 42 0x 43 0x 44 0x 45	If an Accl Trigger is registered while the grace period timer is not currently elapsing, an Accl Event is registered. That is, an Accl Event can only be registered after the grace period timer from the previous Accl Event (if any) has elapsed.
Accl Clear	0x 45	When motion ends and a motion clear report is generated. Specifically, when no additional Accl Triggers are registered for the duration of the grace period timer.

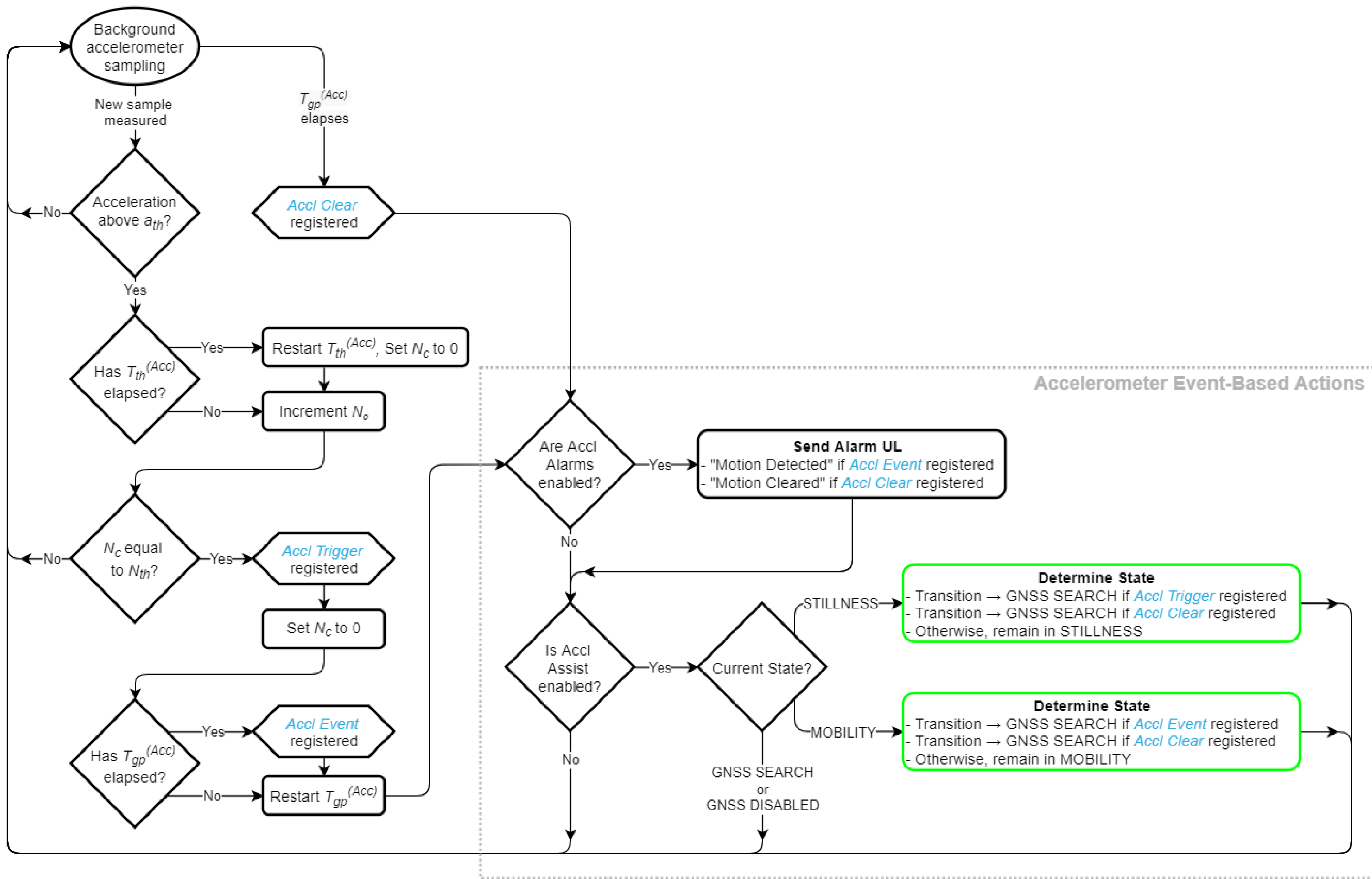


Figure 1-3: The ORCA Accelerometer Event-Based Operational Flow

1.4 BLE Operation

The ORCA supports BLE of Bluetooth 5.0 [4].

The BLE function of the ORCA is Rx only; the ORCA 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 ORCA to then be reported in an UL. This UL is normally reported immediately after the scan concludes but may be delayed due to duty cycle limitations [2]. If a new BLE scan occurs before the results of the previous scan have been sent, the old scan results will be discarded.

The BLE scan can be disabled entirely or enabled at any time. Figure 1-4 shows the BLE scan scheme in the ORCA when the BLE scan is enabled. As shown in the figure, BLE scans are performed periodically with a configurable *scan period*. Each scan lasts for a configurable *scan duration* and is divided into *scan intervals*. The active BLE scan is performed only in the *scan window* portion of the scan interval.

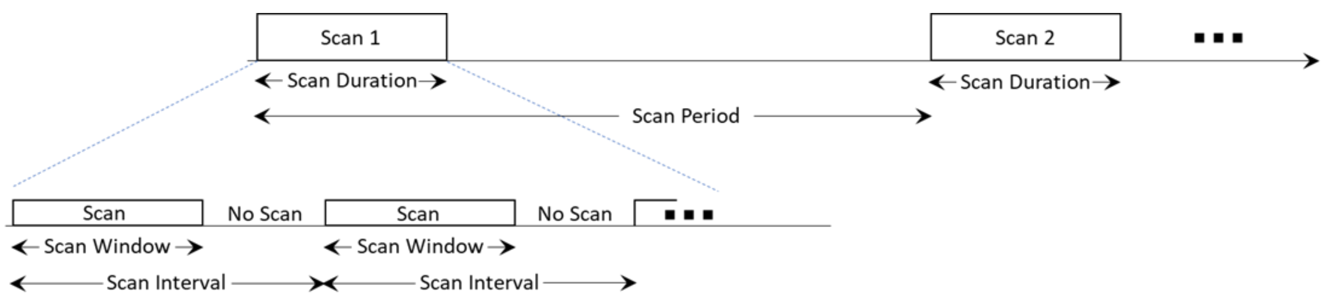


Figure 1-4: The BLE Scan Scheme

There are 3 different scan periods, each for a different internal device state[10]. These scan periods are:

- Default period, $T_D^{(BLE)}$, in the GNSS DISABLED and GNSS SEARCH states.
- STILLNESS period, $T_S^{(BLE)}$, in the STILLNESS state.
- MOBILITY period, $T_M^{(BLE)}$, in the MOBILITY state.

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

[10] See §1.1 for the state machine description.

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 §3.2.3 and §0).

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.

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.

1.5 Magnetic Reed Switch Operation

The ORCA is equipped with a magnetic reed switch. The reed switch can be operated by using a strong magnet to apply either of the following patterns:

A. **Device Reset**:

In all cases, the device reset magnet pattern causes the ORCA to reset. After the reset, 1 of 2 things happen, depending on the state the ORCA was in at the time the pattern was applied[11]:

- If the ORCA was in any state other than JOIN (including DEEP SLEEP) when the pattern was applied, after resetting it will enter JOIN.
- If the ORCA was in JOIN when the magnet pattern was applied, after resetting it will enter DEEP SLEEP.

The device reset magnetic pattern in is illustrated in Figure 1-5. A "magnet presence" is achieved by placing the magnet against the enclosure at the magnet symbol as shown in Figure 1-6. A "magnet absence" is achieved by taking the magnet away from the enclosure. The pattern involves sustaining a "magnet presence" continuously for at least 3 s but less than 10 s.

When the device reset magnetic pattern is applied the ORCA displays an LED indication, described in §1.6, to show that the pattern has been registered.

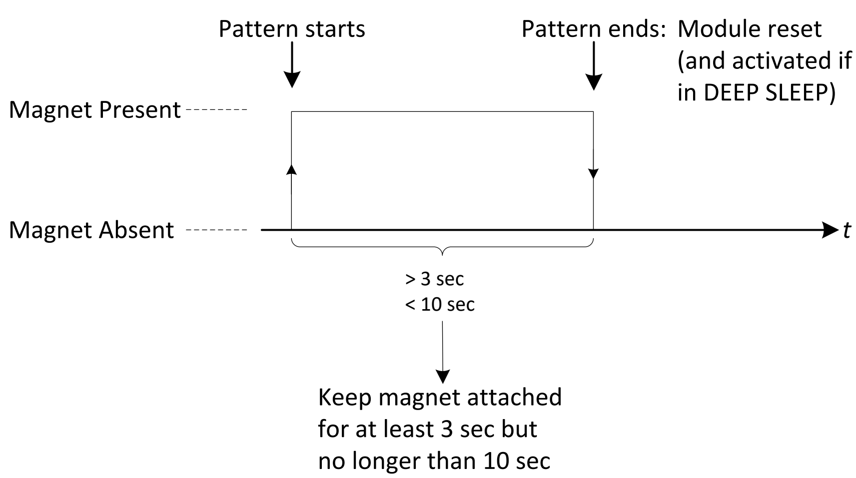


Figure 1-5: The ORCA Magnetic Reset/Wake-Up Pattern

[11] See §1.1 for a description of the state machine.

Figure 1-6: ORCA Enclosure Bottom View Showing Location of Magnet Symbol

B. **Forced UL**:

The forced UL magnetic pattern is used to get the LoRaWAN Class-A ORCA to open a receive window so it can receive DL commands from the NS, or simply to trigger the ORCA to uplink some desired transducer data [1].

The pattern in this case is not user configurable, and involves briefly tapping the magnet symbol (Figure 1-6) once, all in less than 2 s, as shown in Figure 1-7. NOTE: Mistakenly holding the magnet against the enclosure for more than 3 s may trigger a device reset, as explained in item A above.

It is configurable what is uplinked when such a reed switch event is registered. By default, the current FSM state of the ORCA is reported. §3.2.4 describes this configuration.

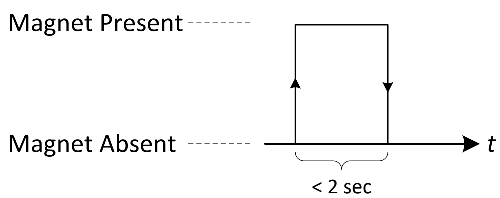


Figure 1-7: The ORCA Magnetic Forced UL Pattern

1.6 LED Behavior

The ORCA is equipped with two on-board LEDs: **GREEN** and **RED**. They are visible through the enclosure at the location shown in Figure 1-8.

Figure 1-8: The ORCA Enclosure Top View Showing Location of LEDs

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 and normal operation.

1.6.1 Power-On and Network Join Operation

After the ORCA is activated (woken up from DEEP SLEEP) or reset (either through a DL reset, magnet reset, or battery replacement), the following LED sequence occurs during the STARTUP state[12].

1. Both **GREEN** and **RED** are off for 10 seconds after any reset occurs (including a wakeup).
2. After 10 seconds, the ORCA SW will conduct its POST. When the POST ends, **GREEN** and **RED** are switched ON for 0.5 seconds, as shown in Figure 1-9.
3. After this, the ORCA will do one of 2 things depending on the results of the POST:
    a. If the POST is successful, the ORCA enters JOIN and begin the join procedure as indicated by the LED pattern explained in step 4.
    b. If the POST fails, the pattern described in step 2 will occur every 10 seconds. If this is the case, the ORCA will not go on to the join procedure in step 4 but will repeat the POST and this LED pattern until the POST passes (if ever).

[12] See §1.1 for a description of the state machine.

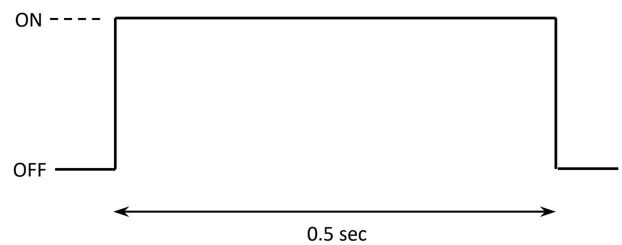


Figure 1-9: The GREEN and RED LED Pattern After POST

4. After a successful POST, both **GREEN** and **RED** are turned off. Immediately following this, the ORCA 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 1-10.
   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.

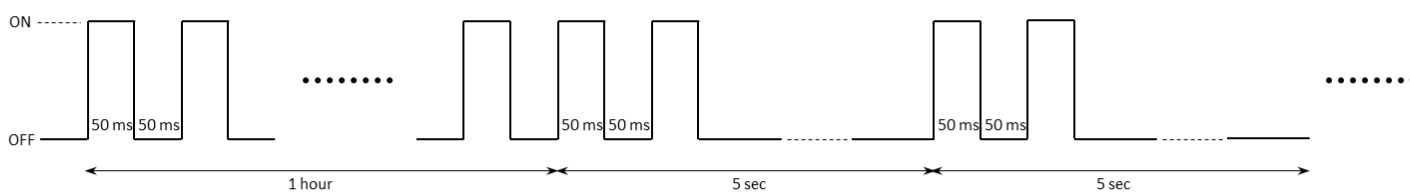


Figure 1-10: The GREEN LED Pattern During the Join Procedure

1.6.2 Normal Operation

After the ORCA 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.

1.6.3 DEEP SLEEP

The ORCA displays an LED indication when it is brought out of DEEP SLEEP. The following LED pattern is displayed immediatelys after the pattern is applied:

1. **GREEN** is toggled ON and OFF every 0.5 sec for 3 sec as shown in Figure 1-11.

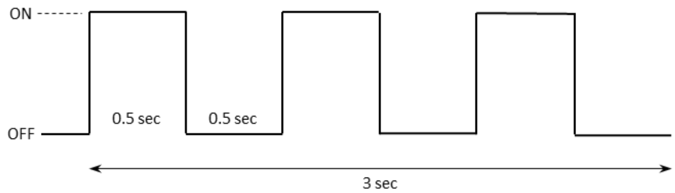


Figure 1-11: The GREEN LED Pattern Upon Waking from DEEP SLEEP

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. The POST pattern as described in steps 1-2 in §1.6.1 occurs.
2. **RED** is toggled ON and OFF every 0.1 sec for 0.6 sec as shown in Figure 1-12.

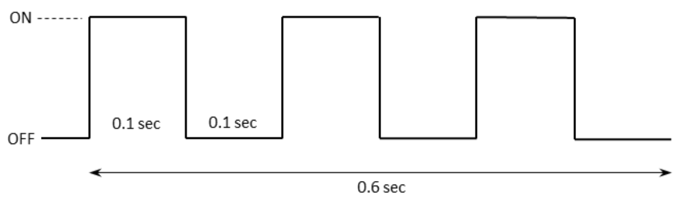


Figure 1-12: The RED LED Pattern Before Entering DEEP SLEEP

2 UL Payload Formats

The UL streams (from the ORCA to the NS) supported by the SW are shown in Table 2-1, and are explained in §2.1 through §2.5.

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**
Return logged (historical) GNSS time and position	**15**
Real-time GNSS diagnostic information	**16**
Discovered BLE devices	**25**
Response to Configuration and Control Commands	**100**

All data contained in Sensor telemetry ULs (not responses to configuration and control commands) falls into one of the following reporting categories:

- **Periodic Reporting**: Scheduled reporting of telemetry at regular, configurable intervals. The reporting intervals are configured using the tick registers as described in §3.2.3.
- **Event-Based Reporting**: Various external events can trigger unscheduled telemetry ULs outside of the periodic reporting schedule. These external events include magnetic switch actuation, motion of the device above the accelerometer threshold criteria, and temperature measurements outside of the threshold window. Each event elicits a different type of response from the Sensor. Not all event-based reporting is enabled by default.

This section describes the *format* of the report payloads. For details on what causes event-based reporting and how to configure the Sensor's event-based behaviour, see the relevant subsections for the transducer of interest in §3.2.

Refer to the ATLAS online application for a comprehensive decoding tool [3].

2.1 Real-Time Sensing Data Report Formats

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

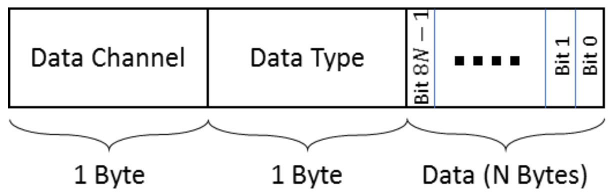


Figure 2-1: The Frame Format of the UL Payload

An ORCA frame payload can include multiple data frames from different sensing entities in the ORCA. Frames can be arranged in any order. The ORCA 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 Formats for Real-Time Sensing Data

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Battery 1 Status	0x 01	0x BA	1 B	(unsigned)	• Bits 0-6 = ($V_{Battery1}$–2.5 V) (10 mV/LSB) • Bit 7: EoS Alert[13] 0/1 = Inactive/Active	*battery1_status {* *voltage: <value>,* *(unsigned/V)* *eos_alert: <value>* *(unsigned/no unit)* *}*
Battery 2 Status	0x 02	0x BA	1 B	(unsigned)	• Bits 0-6 = ($V_{Battery2}$–2.5 V) (10 mV/LSB) • Bit 7: EoS Alert[13] 0/1 = Inactive/Active	*battery2_status {* *voltage: <value>,* *(unsigned/V)* *eos_alert: <value>* *(unsigned/no unit)* *}*

[13] Not supported in FW v0.3.0 and later.

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
UTC	0x 00	0x 85	7 B	Time (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][14]	*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	0x 00	0x 88	9 B	Location (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	0x 00	0x 92	2 B	Rate (unsigned)	0.1 m/s / LSB	*ground_speed: <value> (unsigned/m/s)*
FSM State	0x 00	0x 04	1 B	Counter	• 0 = GNSS DISABLED State • 1 = GNSS SEARCH State • 2 = STILLNESS State • 3 = MOBILITY State	*fsm_state: <value> (unsigned/no unit)*
Fix Status	0x 00	0x 95	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)* *}*

[14] 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)
Geofence Status	0x 01	0x 95	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	0x 00	0x 00	1 B	Digital Input	• 0x 00 = Alarm inactive • 0x FF = Alarm active	*acceleration_alarm: <value> (unsigned/no unit)*
Acceleration Vector	0x 00	0x 71	6 B	Acceleration	• 1 milli-g/LSB (signed) • Bits 32-47: X-axis acceleration • Bits 16-31: Y-axis acceleration • Bits 0-15: Z-axis acceleration	*acceleration_vector { xaxis: <value>, (signed/g) yaxis: <value>, (signed/g) zaxis: <value> (signed/g) }*
MCU Temperature	0x 00	0x 67	2 B	Temperature (signed)	0.1°C/LSB	*temperature: <value> (signed/°C)*

2.1.1 Example Real-Time Sensing Data Frame Payloads

- **0x 00 67 00 EC**
  - 0x 00 67 (MCU Temperature):
    - (0x 00 EC) × 0.1°C = 23.6°C
- **0x 00 67 FF FF 01 BA 63**
  - 0x 00 67 (MCU Temperature):
    - (0x FF FF) × 0.1°C = -0.1°C
  - 0x 01 BA (Battery 1 Status):

    - No EoS alert
    - Voltage = (0x 63) × 0.01 V + 2.5 V = 3.49 V

- **0x 00 95 00 00 71 02 44 00 46 03 3E**
    - 0x 00 95 (Fix Status):
        - (0x 00) = No valid UTC and position fix available
    - 0x 00 71 (Acceleration Vector):
        - X-Axis Acceleration = (0x 02 44) × 0.001 *g* = 0.58 *g*
        - Y-Axis Acceleration = (0x 00 46) × 0.001 *g* = 0.07 *g*
        - Z-Axis Acceleration = (0x 03 3E) × 0.001 *g* = 0.83 *g*

- **0x 00 88 3E 50 B0 BC 02 2D 60 08 2A**
    - 0x 00 88 (Position Coordinates):
        - Latitude = (0x 3E 50 B0) × 0.0000125° = 51.0486°
        - Longitude = (0x BC 02 2D 60) × 0.0000001° = 114.0708°
        - Altitude = (0x 08 2A) × 0.5 m = 1045 m

2.2 Logged GNSS UTC and Position Data Report Formats

The GNSS receiver in the ORCA 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***.

Each log entry contains consists of a pair of corresponding UTC (as the timestamp) and position coordinates from a GNSS fix. Other GNSS data and diagnostics are not logged. The log entries are indexed by *log entry number*, which increments with each new GNSS fix that is logged.

To request retrieval of logged data, the user must send a DL request as described in §3.1.

The payloads to report back requested log entries are in one of three formats shown in Figure 2-2.

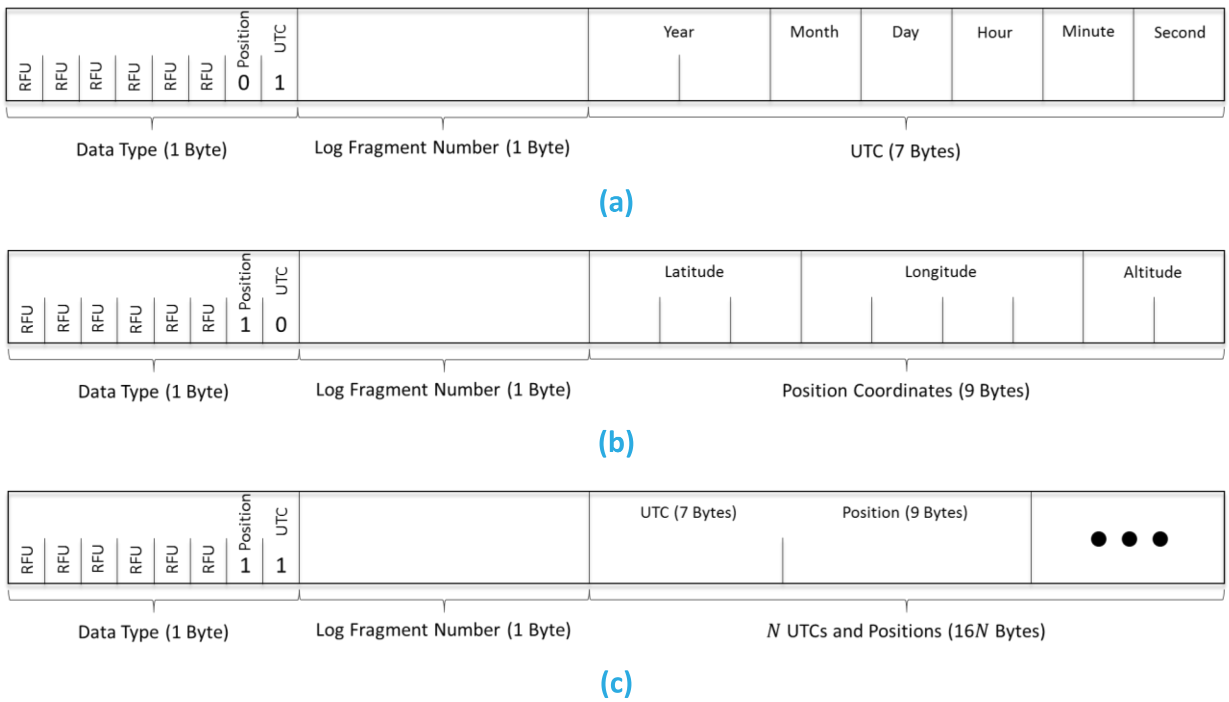


Figure 2-2: The UL Payload Formats for Report GNSS Log Data

Since more than 1 log entry can be requested, sometimes all the log entries requested cannot fit in a single UL payload [2]. In this case, the data to be sent must be fragmented into multiple successive ULs. The *log fragment number* denotes which fragment of the requested data set is in each UL, which can then be used by an application or user to reconstruct the entire message from multiple ULs in the correct order.

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. Formats (a) and (b), two payloads, one of format (a) and one of format (b), are only used when a single payload is not large enough to contain both UTC and position data for 1 log entry. In this case, the log fragment numbers for a corresponding pair of UTC and position in separate ULs will be the same. For example, successive payloads **0x 01 00 U_0**, **0x 02 00 P_0**, **0x 01 01 U_1**, **0x 02 01 P_1**, **0x 01 02 U_2** and **0x 02 02 P_2** can be sent to report log entries (U_0, P_0), (U_1, P_1), and (U_2, P_2), where U_i denotes UTC and P_i denotes position information for the i^{th} log entry requested.

Format (c) is for payloads that contain one or more log entries. For example, payload **0x 03 00 U_0 P_0 U_1 P_1 U_2 P_2** can be sent to report log entries (U_0, P_0), (U_1, P_1), and (U_2, P_2), where U_i denotes UTC and P_i denotes position information for the i^{th} log entry requested.

Depending on the UL DR, a GNSS log may be reported only by payloads of formats (a) and (b), 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.

Latitude, longitude, and altitude are in the same units as reported in real-time GNSS data (see Table 2-2).

A payload consisting of only a one-byte Data Type **0x 00** is transmitted to indicate there is no log entry available to report.

2.2.1 Example Logged GNSS Data Frame Payloads:

- **0x 01 01 07 E7 08 11 16 1E 25**
  - Data type = 0x 01 (UTC)
  - Log fragment number = 0x 01 = #1
  - Year = 0x 07 E7 = 2023
  - Month = 0x 08 = August
  - Day = 0x 11 = 17th
  - Hour:Minute:Second = (0x 16):(0x 1E):(0x 25) = 22:30:37 UTC
- **0x 02 01 3E 50 B0 BC 02 2D 60 08 2A**
  - Data type = 0x 02 (Position Coordinates)
  - Log fragment number = 0x 01 = #1
  - Latitude = (0x 3E 50 B0) × 0.0000125° = 51.0486°
  - Longitude = (0x BC 02 2D 60) × 0.0000001° = -114.0708°
  - Altitude = (0x 08 2A) × 0.5 m = 1045 m

2.3 Real-Time GNSS Diagnostics Report Formats

The ORCA can be enabled to report GNSS diagnostic information obtained during each GNSS search after it concludes[15]. If enabled, diagnostic information is sent through ***LoRaWAN port 16***.

The diagnostic information is encoded in a frame format and bit indexing scheme as shown in Figure 2-1. A big-endian format (MSb/MSB first) is always followed. A frame payload can include multiple diagnostic frames which can be arranged in any order. The frame formats are shown in Table 2-2.

Table 2-3: UL Frame Formats for GNSS Diagnostic Information

Information Type	Channel ID	Type ID	Size	Data Type	Data Format	JSON Variable (Type/Unit)
Number of Visible Satellites	0x 0D	0x 3C	1 B	Integer (unsigned)	• Bits 7-0: Number of satellites used to calculate the GNSS fix. If no fix was obtained, this value is the total number of visible satellites.	*num_satellites: <value> (unsigned/no unit)*
Average Satellite SNR	0x 0D	0x 64	2 B	Generic (signed)	• Bits 15-0: Average SNR of all satellites used to calculate the GNSS fix. (0.1 dB/LSB) • 0x 00 00 = No satellites visible for calculating average	*avg_satellite_snr: <value> (signed/dB)*
Fix Type	0x 0D	0x 95	1 B	Bitmap Input	• 0 = No fix available • 1 = 2D fix • 2 = 3D fix	*fix_type: <value> (unsigned/no unit)*
Time-To-Fix	0x 0D	0x 96	2 B	Stopwatch (unsigned)	• Bits 15-0: The total time that the GNSS receiver has spent scanning for a fix since the last fix was obtained. (1 s/LSB)	*time_to_fix: <value> (unsigned/s)*
Most Recent Log Entry Number	0x 0D	0x 0F	2 B	Integer (unsigned)	• Bits 15-0: Log number of last acquired fix	*log_num: <value> (unsigned/no unit)*
Ghost Error Count	0x 0D	0x 04	2 B	Counter (unsigned)	• Bits 15-0: Count of how many time the GNSS module returned a "ghost" fix	*ghost_error_count: <value> (unsigned/no unit)*

[15] See §3.2.5.3 for GNSS diagnostic reporting configuration details and definitions of each diagnostic.

2.3.1 Example Real-Time GNSS Diagnostics Frame Payloads

- **0x 0D 3C 06 0D 95 02**
  - 0x 0D 3C (Number of Visible Satellites):
    - 0x 06 = 6 satellites
  - 0x 0D 95 02 (Fix Type)
    - 0x 02 = 3D fix
- **0x 0D 04 27 0F**
  - 0x 0D 04 (Most Recent Log Entry Number):
    - 0x 27 0F = Log entry #9999

2.4 Discovered BLE Devices Report Format

For information about how BLE scans are conducted and how discovered device data is handled, see §1.4.

If BLE is enabled, periodic scans are conducted to search for nearby advertising BLE peripheral devices. During each scan, if a BLE advertisement packet is received by the ORCA, the BLE device from which that advertisement originated is referred to as a *discovered device*. Discovered devices are reported on ***LoRaWAN port 25*** with one of the formats shown in Figure 2-3.

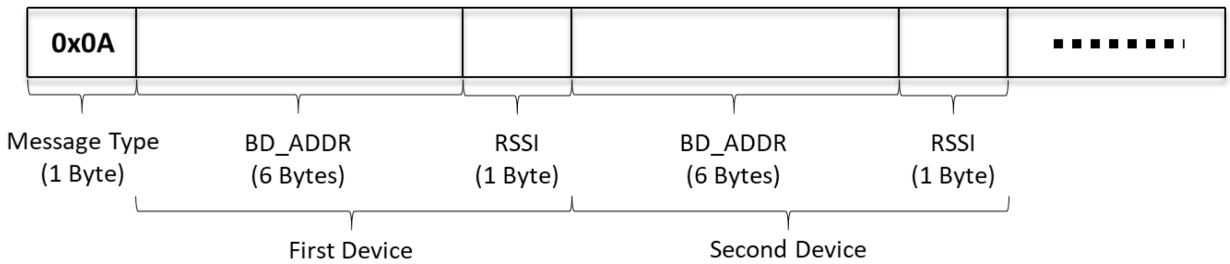
With *basic* reporting enabled (Figure 2-3(a)), the message type header is 0x 0A. The BD_ADDR for each discovered device is a full 6-byte MAC address, and is followed by the device RSSI, which is a signed one-byte number in units of dBm.

With *filtered* reporting (Figure 2-3(b)–(e)), up to 4 ranges of BD_ADDR can be defined for filtering discovered devices (see Section 0). The message type headers 0x B0, 0x B1, 0x B2, and 0x B3 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.

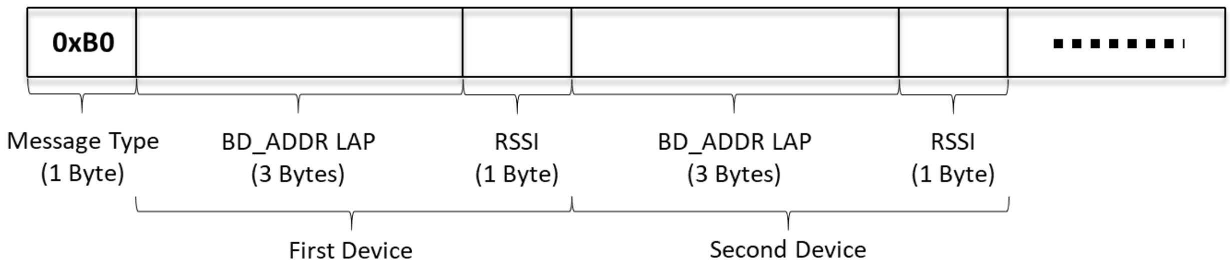
For example, if the only discoverable BLE devices of interest all have MAC addresses that begin with 647FDA (OUI) and only the last 3 bytes are different for each device (LAPs), the BD_ADDR range to filter for only these devices would be 647FDA:000000-FFFFFF. In other words, this BD_ADDR range means that the ORCA will filter the discovered devices to include only those with MAC addresses from 647FDA000000 to 647FDAFFFFFFF, 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 [2]. See §1.4 for how many and which 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 0) 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.

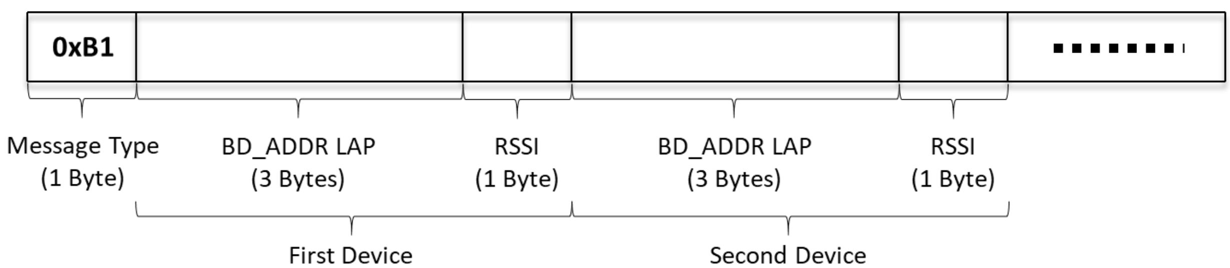
The scan results are normally reported in a UL immediately after the scan concludes but may be delayed due to duty cycle limitations [2]. If a new BLE scan occurs before the results of the previous scan have been sent, the old scan results will be discarded.



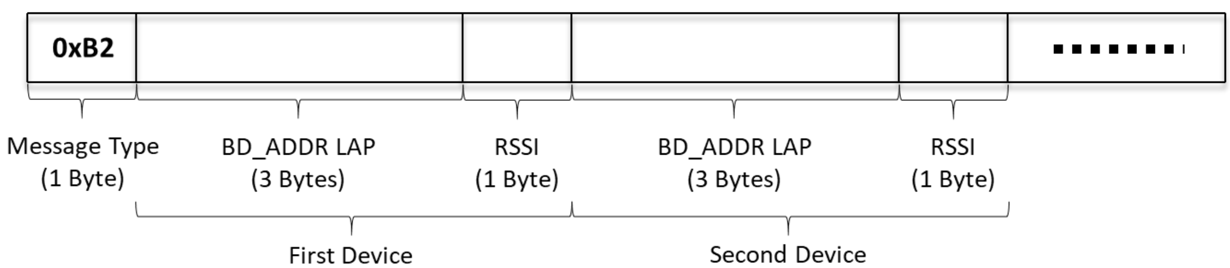
(a) Basic reporting.



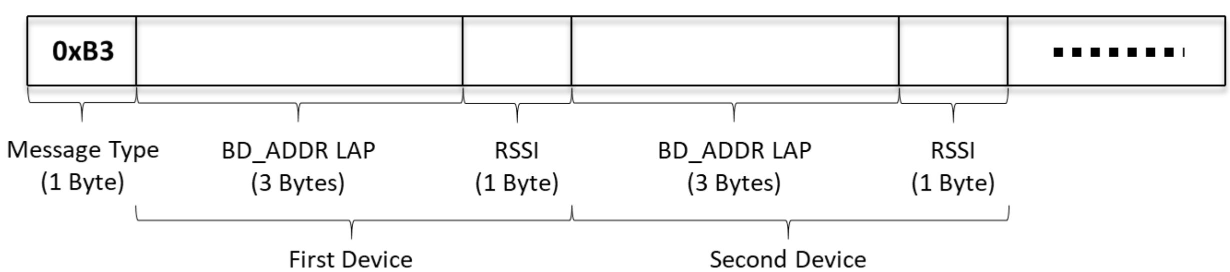
(b) Filtered reporting, Range 0.



(c) Filtered reporting, Range 1.



(d) Filtered reporting, Range 2.



(e) Filtered reporting, Range 3.

Figure 2-3: The UL Frame Formats for Reporting Discovered BLE Devices

2.4.1 Example Discovered BLE Devices Frame Payloads

- **0x 0A 64 7F DA 12 34 56 CF**
    - Report Type = 0x 0A = Basic report
    - MAC Address = 0x 64 7F DA 12 34 56 = 647FDA123456
    - RSSI = 0x CF = -49 dBm
- **0x B0 01 A8 61 C1 01 82 21 AD**
    - Report Type = 0x B0 = Filtered report, range 0
    - 1st Device LAP = 0x 01 A8 61 = 01A861
    - 1st Device RSSI = 0x C1 = -63 dBm
    - 2nd Device LAP = 0x 01 82 21 = 018221
    - 2nd Device RSSI = 0x AD = -83 dBm
- **0x B3**
    - Report Type = 0x B3 = Filtered report, range 3
    - No devices in range 3 discovered

2.5 Response to Configuration and Control Commands Formats

The ORCA responses to DL configuration and control commands (see §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 ORCA responds with 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 ORCA 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 ORCA response in the former case).

2.5.1 Example Response to Configuration and Control Commands Frame Payloads

- **0x 20 00 00 00 3C 21 00 01**
  - Register 0x 20 (seconds per core tick)
    - Value = 0x 00 00 00 3C = 60 s per core tick
  - Register 0x 21 (ticks per battery report)
    - Value = 0x 00 01 = 1 tick per battery report
- **0x 81 03 E8 5B**
  - 4B CRC in response to a write command DL

3 Configuration Settings and DL Payload Formats

The DL streams (from the NS to the ORCA) supported by the SW are shown in Table 3-1, and are explained in §3.1 and §3.2.

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**

DLs are used for the following purposes:

1. To read the current configuration of the ORCA.
2. To change the current configuration of the ORCA.
3. To cause the ORCA to perform an operation, such as reset.

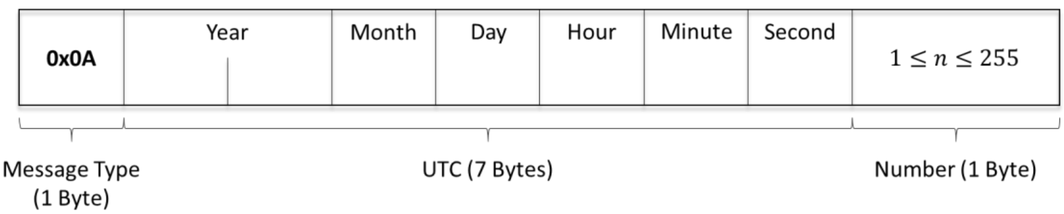
Refer to the ATLAS online application for a comprehensive DL encoding tool [3].

3.1 Requesting GNSS Logged Data

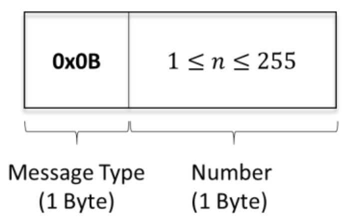
The GNSS receiver in the ORCA logs GNSS information as time and position fixes are obtained. These fixes can be retrieved later from the GNSS receiver flash and reported OTA.

Each log entry contains consists of a pair of corresponding UTC (as the timestamp) and position coordinates from a GNSS fix. Other GNSS data and diagnostics are not logged. The log entries are indexed by *log entry number*, which increments with each new GNSS fix that is logged.

To request retrieval of logged data, the user must send a DL request on ***LoRaWAN port 15***. This request can be formulated in one of 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., 0x 0A or 0x 0B).



(a) Type A GNSS Log Request



(b) Type B GNSS Log Request

Figure 3-1: DL Payload Format Types for Requesting GNSS Logged Data

The Type A request contains a UTC timestamp and a number, n, where $1 \leq n \leq 255$. By sending this request, the user is telling the ORCA to retrieve n GNSS log entries (time and position fixes) before the timestamp from the logged historical data.

The Type B request contains only n. By sending this request, the user is telling the ORCA to retrieve the last (most recent) n GNSS log entries (time and position fixes).

Upon receiving a GNSS log request, the ORCA responds with the requested GNSS log on ***LoRaWAN port 15***, as explained in §2.2.

3.1.1.1 Example GNSS Logged Data Request Formats

- User requests the last 60 log entries prior to August 17th, 2023:
    - DL payload: **0x 0A 07 E7 08 11 00 00 00 3C**

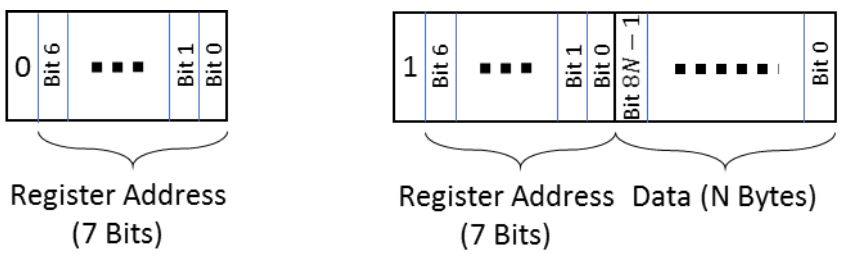
        - Request type = 0x 0A (Type A)
        - Year = 0x 07 E7 (2023)
        - Month = 0x 08 (August)
        - Day = 0x 11 (17^{th})
        - Hour:Minute:Second = (0x 00):(0x 00):(0x 00) = 00:00:00 UTC
        - n = 0x 3C (60 log entries)
- User requests the most recent log entry:
    - DL payload: **0x 0B 01**
        - Request type = 0x 0B (Type B)
        - n = 0x 01 (1 log entry)

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

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 0x 00 and 0x 7F, inclusive.

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.



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

Figure 3-2: The DL Format for Configuration and Control Message Blocks

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

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

DL configuration and control commands fall into one of the following categories and are discussed in §3.2.2 through §3.2.9:

- LoRaMAC Configuration
- Periodic Tx Configuration
- Reed Switch Configuration

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

3.2.1.1 Example Read and Write Commands

- Read registers 0x 10, 0x 11, and 0x 12:
    - DL payload: **0x 10 11 12**
        - Register 0x 10 with bit 7 set to 0 = 0x 10
        - Register 0x 11 with bit 7 set to 0 = 0x 11
        - Register 0x 12 with bit 7 set to 0 = 0x 12
- Read register 0x 13 and write value 0x 80 00 to register 0x 10:
    - DL payload: **0x 13 90 80 00**
        - Register 0x 13 with bit 7 set to 0 = 0x 13
        - Register 0x 10 with bit 7 set to 1 = 0x 90
        - Value 0x 80 00

3.2.2 LoRaMAC Configuration

The LoRaMAC configuration options change certain LoRaWAN-specified MAC configuration parameters that the ORCA loads on start-up and uses during run-time [1], [2]. Table 3-2 shows the MAC configuration registers. In this table, the bit indexing scheme is as shown in Figure 3-2.

Table 3-2: LoRaMAC Configuration Registers

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x 10	Join Mode	2 B	• Bit 15: 0/1 = ABP/OTAA mode • Bits 0-14: Ignored	OTAA mode **0x 80 00**	*loramac_join_mode: <value>* *(unsigned/no unit)*
0x 11	Options	2 B	• 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[16] • Bit 3: 0/1 = ADR disabled/enabled • Bits 4-15: Ignored	• Unconfirmed UL • Public Sync Word • Duty cycle enabled[16] • ADR enabled **0x 00 0E**	*loramac_opts {* *confirm_mode: <value>,* *(unsigned/no unit)* *sync_word: <value>,* *(unsigned/no unit)* *duty_cycle: <value>,* *(unsigned/no unit)* *adr: <value>* *(unsigned/no unit)* *}*
0x 12	DR and Tx Power	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) [17] **0x 00 00**	*loramac_dr_tx {* *dr_number: <value>,* *(unsigned/no unit)* *tx_power_number: <value>* *(unsigned/no unit)* *}*
0x 13	Rx2 Window	5 B	• Bits 8-39: Channel frequency in Hz for Rx2 • Bits 0-7: DR for Rx2	As per Table 3-3	*loramac_rx2 {* *frequency: <value>,* *(unsigned/Hz)* *dr_number: <value>* *(unsigned/no unit)* *}*

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

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

Table 3-3: Default Max Tx Power, Rx2 Channel Frequency, and Rx 2 DR Number by Regions

RF Region	Max Tx EIRP[18] [dBm]	Channel Frequency for Rx2 Window [Hz]	DR Number for Rx2 Window
EU868	16	869525000	0
US915	30	923300000	8
AS923	16	923200000	2
AU915	30	923300000	8
IN865	30	866550000	2
KR920	14	921900000	0
RU864	16	869100000	0

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

3.2.2.1 Example LoRaMAC Configuration DL Payloads

- Switch Device to ABP Mode:
  - DL payload: **0x 90 00 00**
    - Register 0x 10 with bit 7 set to 1 = 0x 90
    - Desired option: register value with bit 15 set to 0 = 0x 00 00
- Disable ADR, keep Duty Cycle enabled, and use confirmed ULs:
  - DL payload: **0x 91 00 07**
    - Register 0x 11 with bit 7 set to 1 = 0x 91
    - Desired options: register value with bit 3 set to 0, bit 2 set to 1, bit 1 set to 1, and bit 0 set to 1 = 0x 00 07
- Set default DR number to 3, default Tx power number to 4, and read the current Rx2 settings:
  - DL payload: **0x 92 03 04 13**
    - Register 0x 12 with bit 7 set to 0 = 0x 92
    - DR3 = 0x 03
    - Tx 4 = 0x 04
    - Register 0x 13 with bit 7 set to 0 = 0x 13

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[18] These are Tx power *setpoints* and are the maximum allowable by the LoRaWAN regional parameters specification [2]. The actual Tx power of the ORCA is limited by the radio transceiver, which is 20 dBm. Therefore, a setpoint greater than 20 dBm will be equivalent to a setpoint of 20 dBm or the Max Tx EIRP for the region, whichever is lower.

3.2.3 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 ORCA measurements and reports. For each transducer or subsystem in the ORCA, the number of elapsed ticks before transmitting can be defined. Table 3-4 shows a list of registers used to configure the ORCA periodic transmissions. All the registers have R/W access. Note that these registers only control *periodic reporting* and do not affect *event-based reporting* of the same type of telemetry (see §2).

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

<Transducer> *Reporting Period* = *Seconds per Core Tick* × *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", "MCU Temperature", or "FSM State", as shown in Table 3-4. 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 3-4: Periodic Transmission Configuration Registers

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x 20	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 **0x 00 00 0E 10**	*seconds_per_core_tick: <value> (unsigned/sec)*
0x 21	Ticks per Battery	2 B	• Ticks between battery reports • 0 disables periodic battery reports	24 ticks = 1-day period **0x 00 18**	*ticks_per_battery: <value> (unsigned/no unit)*
0x 22	Ticks per GNSS in STILLNESS State	2 B	• Ticks between GNSS reports (data and/or diagnostics) in STILLNESS state • 0 disables periodic GNSS reports in STILLNESS state	1 tick = 1-hour period **0x 00 01**	*ticks_per_gnss_stillness: <value> (unsigned/no unit)*
0x 23	Ticks per GNSS in MOBILITY State	2 B	• Ticks between GNSS reports (data and/or diagnostics) in MOBILITY state • 0 disables periodic GNSS reports in MOBILITY state	1 tick = 1-hour period **0x 00 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 **0x 00 00**	*ticks_per_accelerometer: <value> (unsigned/no unit)*

Address	Value	Size	Description	Default Value	JSON Variable (Type/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	1 tick = 1-hour period **0x 00 01**	*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	Periodic reporting disabled **0x 00 00**	*ticks_per_ble_stillness: <value> (unsigned/no unit)*
0x 27	Ticks per BLE in MOBILITY State	2 B	• Ticks between BLE reports in MOBILITY state • 0 disables periodic BLE reports in MOBILITY state	Periodic reporting disabled **0x 00 00**	*ticks_per_ble_mobility: <value> (unsigned/no unit)*
0x 28	Ticks per MCU Temperature	2 B	• Ticks between temperature reports • 0 disables periodic temperature reports	Periodic reporting disabled **0x 00 00**	*ticks_per_mcu_temperature: <value> (unsigned/no unit)*
0x 29	Ticks per FSM State	2 B	• Ticks between FSM state reports • 0 disables periodic FSM state reports	Periodic reporting disabled **0x 00 00**	*ticks_per_fsm_state: <value> (unsigned/no unit)*

NOTE 1: For best results it is not recommended to set the GNSS report period in STILLNESS or MOBILTITY to less than 3.5 min. Refer to §3.2.3.2 for best practices regarding GNSS and BLE reporting period configuration.

NOTE 2: The first periodic report for every enabled report type occurs right after the ORCA successfully joins the network. That is, tick 1 occurs right after successful join. A consequence of this is that, using the default battery reporting configuration as an example, the first battery report will occur immediately after join but the next one will occur 23 hours later (every one thereafter will occur at the expected 24 hour intervals).

3.2.3.1 Example Periodic Configuration DL Payloads

- Read current value of Seconds per Core Tick:
  - DL payload: **0x 20**
    - Register 0x 20 with bit 7 set to 0 = 0x 20
- Change settings to report GNSS data/diagnostics every 15 minutes, regardless of ORCA motion state:
  - DL payload: **0x A0 00 00 01 2C A2 00 01 A3 00 01**

- Register 0x 20 with bit 7 set to 1 = 0x A0
- Seconds per core tick = 300 s = 0x 00 00 01
- Register 0x 22 with bit 7 set to 1 = 0x A2
- Ticks per GNSS in STILLNESS = 1 tick = 0x 00 01
- Register 0x 23 with bit 7 set to 1 = 0x A3
- Ticks per GNSS in MOBILITY = 1 tick = 0x 00 01

3.2.3.2 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 3.5 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 ORCA will attempt to acquire satellite data in the GNSS SEARCH state until it either gets a valid fix or a 3.5-minute timeout elapses. Afterwards, the results of that search are sent in a LoRaWAN 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 timeout will expire. Therefore, if the ORCA 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 3.5 minutes and the ORCA is located in a poor-GNSS signal area.

For BLE report period recommendations, refer to Section 3.2.7.4.

3.2.3.3 Anti-Bricking Strategy

Since the magnetic reed switch functionality cannot be disabled (see Sections 1.5 and 3.2.4), it is impossible to completely brick the ORCA with a bad configuration; i.e., it is always possible to trigger the ORCA 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 ORCA may not be convenient or even possible, e.g. due to special mounting or volume of deployed ORCAs.

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

After any configuration change on registers 0x 21 to 0x 29, if all periodic reporting becomes disabled, or the minimum period in enabled periodic reporting becomes larger than a day (86,400 sec), then register 0x 21 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 0x 21 is set to $\left\lfloor \frac{\mathbf{86400}}{\textbf{Value of register } \mathbf{0}\boldsymbol{x}\mathbf{20}} \right\rfloor$***, where*** $\lfloor . \rfloor$ ***is the floor function.***

3.2.4 Magnetic Reed Switch Configuration

The ORCA 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 1.5). They type of data sent in such an uplink is configurable (by default the current FSM state is reported). The reed switch functionality cannot be disabled.

Table 3-5 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 ORCA 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.

There are certain bit configurations where report UL with **no frame payload** is sent upon magnet trigger:

- When all data types are disabled.
- When acceleration vector is enabled but the accelerometer is disabled (register 0x 40), and all other data types are disabled.
- When BLE report is enabled but BLE function is disabled (register 0x 50), and all other data types are disabled.
- When GNSS log report is enabled but there is no logged GNSS data, and all other data types are disabled.

Table 3-5: Magnetic Reed Switch Configuration Register

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x 2A	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 **0x 00 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)* *}*

3.2.4.1 Example Magnetic Reed Switch Configuration DL Payloads

- Read current value of *Value to Tx*:
  - DL payload: **0x 2A**
    - Register 0x 2A with bit 7 set to 0 = 0x 2A
- Report BLE data and MCU temperature with every magnet trigger:
  - DL payload: **0x AA 00 0C**
    - Register 0x 2A with bit 7 set to 1 = 0x AA
    - Desired options: register value with bits 2 and 3 set to 1, all other bits set to 0 = 0x 00 0C

3.2.5 GNSS Configuration

Table 3-6 shows a list of configuration registers for the ORCA'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 3-6: GNSS Receiver Configuration Registers

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x 30	Mode	1 B	• Bits 0-6: Ignored • Bit 7: 0/1 = GNSS receiver disabled/enabled	GNSS receiver enabled **0x 80**	*gnss_enabled: <value>* *(unsigned/no unit)*
0x 31	Ground Speed Threshold	2 B	• Bits 8-15: Mobility Ground Speed Threshold (0.1 m/s / LSB) • Bits 0-7: Invalid and ignored	• Mobility threshold = 3 m/s **0x 1E 0A**	*speed_threshold: <value> (unsigned/m/s)*
0x 32	GNSS Diagnostics Value to Tx	1 B	• Bit 0: 0/1 = Number of Visible Satellites report disabled/enabled • Bit 1: 0/1 = Average Satellite SNR report disabled/enabled • Bit 2: 0/1 = Fix Type report disabled/enabled • Bit 3: 0/1 = Time-To-Fix report disabled/enabled • Bit 4: 0/1 = Most Recent Log Entry # report disabled/enabled • Bit 5: 0/1 = Ghost Error Count report disabled/enabled • Bits 6-7: Ignored	No diagnostics reported **0x 00**	*gnss_diagnostics_tx {* *num_satellites: <value>, (unsigned/no unit)* *avg_satellite_snr: <value>, (unsigned/no unit)* *fix_type: <value>, (unsigned/no unit)* *time_to_fix: <value> (unsigned/no unit)* *log_num: <value> (unsigned/no unit)* *ghost_error_cnt: <value> (unsigned/no unit)* *}*

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x 33	GNSS Data 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 all = 0: Invalid and ignored • Bits 4-7: Ignored	UTC and Position Coordinates reports enabled **0x 03**	*gnss_data_tx {* *utc: <value>, (unsigned/no unit)* *coordinates: <value>, (unsigned/no unit)* *ground_speed: <value>, (unsigned/no unit)* *geofence: <value> (unsigned/no unit)* *}*
0x 34	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 **0x 00 00 00 00 00 00 00 00**	*geofence0 {* *latitude: <value>, (signed/°)* *longitude: <value>, (signed/°)* *radius: <value> (unsigned/m)* *}*
0x 35	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 **0x 00 00 00 00 00 00 00 00**	*geofence1 {* *latitude: <value>, (signed/°)* *longitude: <value>, (signed/°)* *radius: <value> (unsigned/m)* *}*

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x 36	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 **0x 00 00 00 00 00 00 00 00**	*geofence2 {* *latitude: <value>, (signed/°)* *longitude: <value>, (signed/°)* *radius: <value> (unsigned/m)* *}*
0x 37	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 **0x 00 00 00 00 00 00 00 00**	*geofence3 {* *latitude: <value>, (signed/°)* *longitude: <value>, (signed/°)* *radius: <value> (unsigned/m)* *}*

3.2.5.1 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 GNSS searches are conducted.

3.2.5.2 Ground Speed Threshold

Register 0x 31 defines the Ground Speed Threshold. The GNSS receiver obtains (2-D) ground speed of the ORCA as part of each fix. This is used to determine what the internal state of the ORCA should be after each GNSS SEARCH ends; see §1.1 for the state machine description.

3.2.5.3 GNSS Diagnostics Value to Tx

Following the conclusion of a GNSS SEARCH, the user can choose which, if any, diagnostic information is transmitted. The periods for reporting depend on the current motion state of the device and are controlled by registers 0x 22 and 0x 23 (ref. §3.2.3). The reports are sent on ***LoRaWAN port 16*** and the formats are as described in §2.3.

Available diagnostics value options to report are:

- *Number of Visible Satellites:* number of satellites detected by the GNSS antenna during the last GNSS SEARCH. If a fix is obtained following the search, this value only represents the number of satellites used to calculate the fix data that is reported (ref. §3.2.5.4). If a fix cannot be obtained, this value represents all visible satellites.

- *Average Satellite SNR*: the average signal-to-noise ratio of all satellites used to calculate the fix in the results of the last GNSS SEARCH. If no satellites were visible, a value of 0x 00 00 is transmitted.

- *Fix Type*: whether the reported fix was a 2D or 3D fix. If no fix was available, a value of 0x 00 is transmitted.

- *Time-To-Fix* (*TTF*): the time, in seconds, that it took to obtain the fix, i.e., the length of time between the beginning of the GNSS SEARCH and the moment a fix could be obtained. Each time a valid fix is obtained, the TTF value is reset to 0 after reporting the fix data in a LoRa UL. If no fix is obtained before the search is cut off (210 s), then the TTF value is not reset to 0. That is, at the time the next GNSS SEARCH begins after a search that resulted in no fix, the TTF during the new search is added to the existing value.

- *Most recent log entry number*: The device stores every fix obtained during a GNSS SEARCH state in the GNSS log under an incrementing log number. If this option is enabled, the most recent log entry number is transmitted, even if no new fixes were acquired during the last GNSS SEARCH. See §1.2.2 for a description of the GNSS log functionality.

- *Ghost Error Count*: Sometimes the GNSS UL contains a "ghost" fix, which is a coordinates + UTC data pair that is erroneously retrieved from an older time in the GNSS log. A ghost packet can be identified by the UTC being older than the previous UTC that was reported. To count how often this occurs in FW, a counter increments with every instance.

NOTE: If there are no GNSS data (see §3.2.5.4) available at the time the report is due, but any combination of the GNSS diagnostics report options are enabled, these values are sent anyways. I.E.: regardless of whether the device can obtain a valid UTC or Position fix at the time a report is due, the other enabled reporting values listed above are still reported.

3.2.5.4 GNSS Data Value to Tx

Following the conclusion of a GNSS SEARCH, the user can choose which, if any, search results data types are transmitted. The periods for reporting depend on the current motion state of the device and are controlled by registers 0x 22 and 0x 23 (ref. §3.2.3). The reports are sent on ***LoRaWAN port 10*** and the formats are as described in §2.1.

Available data value types to report are:

- *UTC*: UTC time of the obtained 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 ORCA in multiples of 0.1 m/s.
- *Geofence Status*: Status of the obtained fix, either "unknown", "inside", or "outside" relative to each geofence. See §3.2.5.5 for geofence functionality.

NOTE: A single GNSS Fix Status message (with header 0x 00 95, as shown in §2.1.1) 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.

3.2.5.5 Geofence Definition Registers

The ORCA supports setting up to 4 *geofences.* 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 ORCA to send status information about whether it is located inside or outside of a geofence, or if the status is unknown. Each geofence area is a circle and is defined by the latitude and longitude of its center and its radius.

The *Geofence Definition* registers are used to define up to 4 geofences that can be activated on an ORCA. 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 ORCA enables that geofence.

Whenever geofence status is due to be reported, the status of all geofence areas will be included in the LoRaWAN UL (see §2.1 for report format), regardless of whether they are enabled/ or disabled.

When a geofence is undefined/disabled, the geofence status returned is "unknown."

3.2.5.6 Example GNSS Configuration DL Payloads

- Read current value of *GNSS Mode*:
  - DL payload: **0x 30**
    - Register 0x 30 with bit 7 set to 0 = 0x 30
- Disable UTC and coordinate reporting and enable ground speed reporting:

- DL payload: **0x B2 04**
    - Register 0x 32 with bit 7 set to 1 = 0x B2
    - Desired options: bit 3 set to 1, all other bits set to 0 = 0x 04

3.2.6 Accelerometer Configuration

The accelerometer in the ORCA can be disabled or enabled (it is enabled by default). It supports both periodic and event-based reporting.

For a detailed description of how the accelerometer functionality works, refer to §1.3.

Table 3-7 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 3-7: Accelerometer Configuration Registers

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x 40	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 **0x C7**	*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)* *}*
0x 41	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): 0/1/2/3 = ±2/±4/±8/±16 *g* • Bits 3, 6, 7: Ignored	• Sample Rate = 10 Hz • Measurement Range = ±8 *g* **0x 22**	*accelerometer_sensitivity {* *sample_rate: <value>, (unsigned/Hz)* *measurement_range: <value> (unsigned/g)* *}*

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x 42	Acceleration Trigger Threshold Count	2 B	• Number of above-threshold accelerations samples before an acceleration event is registered • Acceptable values: ≥ 1	1 sample **0x 00 01**	*accl_event_threshold_count: <value> (unsigned/no unit)*
0x 43	Acceleration Trigger Threshold Period	2 B	• Period in s over which above-threshold acceleration samples are counted for threshold detection • Acceptable values: ≥ 5	10 seconds **0x 00 0A**	*accl_event_threshold_period: <value> (unsigned/s)*
0x 44	Acceleration Trigger Threshold	2 B	• Unsigned, 1 milli-g/LSB	800 mg **0x 03 20**	*acceler_trigger_threshold: <value> (unsigned/g)*
0x 45	Acceleration Alarm Grace Period	2 B	• Time in s to pass after the last acceleration event before the next acceleration event can be registered • Acceptable values: ≥ 15	5 min **0x 01 2C**	*acceleration_alarm_grace_period: <value> (unsigned/s)*
0x 46	Acceleration Alarm Enabled	1 B	• Bit 0: 0/1 = Acceleration alarm disabled/enabled • Bits 1-7: Ignored	Alarm Enabled **0x 01**	*acceleration_alarm_enabled: <value> (unsigned/no unit)*

3.2.6.1 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 triggers and its corresponding value in the output acceleration vector is 0.

The *Mode* register also controls, via the Accelerometer Assist bit, whether a registered acceleration trigger or acceleration clear triggers a transition to the GNSS SEARCH state, as explained in §1.3.

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

3.2.6.2 Sensitivity

When enabled, the accelerometer samples at a fixed rate, called the *Sample Rate*. To capture an acceleration trigger, the physical acceleration needs to sustain for 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.

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. All output acceleration values on any given axis (X, Y, or Z), is an 8-bit signed number, so 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: If the threshold configured in register 0x 44 is equal to or greater than the configured measurement range then no acceleration event will ever be registered.

3.2.6.3 Acceleration Trigger Threshold Count

By default, the accelerometer registers an acceleration trigger each time it detects above-threshold 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.

3.2.6.4 Acceleration Trigger Threshold Period

The *Acceleration Event Threshold Period* is the amount of time that above-threshold acceleration samples are accumulated for trigger detection. For example, a period of 10 s means that acceleration samples are accumulated for 10 s from the time of first above-threshold detection. An acceleration trigger is registered only if the *Acceleration Trigger Threshold Count* is reached before the period timeout expires.

3.2.6.5 Acceleration Trigger Threshold

This parameter is the g-threshold that an acceleration sample must be greater than or equal to for it to be counted towards an acceleration trigger.

3.2.6.6 Acceleration Event Grace Period

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

3.2.6.7 Acceleration Alarm Enabled

The accelerometer event-based reporting is disabled or enabled through this register (it is enabled by default). If disabled, no “motion detected” alarm or “motion clear” alarms are reported OTA.

3.2.6.8 Example Accelerometer Configuration DL Payloads

- Read current value of acceleration trigger threshold:
  - DL payload: **0x 44**
    - Register 0x 44 with bit 7 set to 0 = 0x 44
- Disable Accelerometer Assist feature and set accelerometer trigger threshold count to 10:
  - DL payload: **0x C0 87**
    - Register 0x 40 with bit 7 set to 1 = 0x C0
    - Desired options: bits 1, 2, 3, and 7 set to 1, all others set to 0 = 0x 87
    - Register 0x 42 with bit 7 set to 1 = 0x C2
    - 10 counts = 0x 00 0A

3.2.7 BLE Configuration

The BLE module is embedded in the MCU. It acts as a BLE central device that conducts periodically and/or event-based scans to discover nearby BLE peripherals. It can be used as a standalone proximity sensor used for positioning. See §1.4 for details about how BLE operates in the ORCA.

Table 3-8 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 3-8: BLE Configuration Registers

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x 50	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) **0x 08**	*ble_mode: {* *num_reported_devices: <value>,* *(unsigned/no unit)* *repetition_enabled: <value>* *(unsigned/no unit)* *}*
0x 51	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 **0x 01 03**	*ble_scan_duration: {* *event_based: <value>,* *(unsigned/sec)* *periodic: <value>* *(unsigned/sec)* *}*
0x 52	Scan Interval	2 B	• Scan interval (1 ms/LSb) • Acceptable values: 3, …, 10000 • Other values: Invalid and ignored	30 ms **0x 00 1E**	*ble_scan_interval: <value>* *(unsigned/sec)*

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x 53	Scan Window	2 B	• Scan window (1 ms/LSb) • Acceptable values: 3, …, “Scan Interval” • Other values: Invalid and ignored	30 ms **0x 00 1E**	*ble_scan_window: <value>* *(unsigned/sec)*
0x 54	Filter Range 0	9 B	• 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 **0x 00 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)* *}*
0x 55	Filter 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 **0x 00 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)* *}*
0x 56	Filter 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 **0x 00 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)* *}*

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x 57	Filter 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 **0x 00 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)* *}*

3.2.7.1 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 §1.4, it is possible to observe more than 1 advertisement from a single peripheral BLE device during one ORCA scan duration. The repetition mode bit of reg 0x 50 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 advertisement that was detected during the ORCA'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*** detected advertisements during the ORCA's scan, regardless of which BLE devices they are from.

Reg 0x 50 also controls whether BLE scanning is disabled entirely.

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

3.2.7.1 Scan Duration, Interval, and Window.

Figure 1-4 shows the BLE scan scheme in the ORCA. As shown in the figure, BLE scans are performed periodically with a configurable *scan period*, which depends on the current motion state of the ORCA[19]. Each scan lasts for a configurable *scan duration* and is divided into *scan intervals*.

[19] See §3.2.3 for configuration of the different BLE reporting periods and Figure 1-1 for when each is used.

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 3-8, the scan duration can be set independently for periodic and event-based reports through register 0x 51. 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 3.2.4). The other BLE scan configuration parameters (number of reported devices, scan interval, and scan window) remain the same for both periodic and event-based scans.

3.2.7.2 Filtering

As explained in §1.4, 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 filter ranges are reported. Up to 4 filter ranges can be defined through registers 0x 54 to 0x 57.

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 filter range is 9 bytes and formatted as $OUI|LAP_{start}|LAP_{end}$ that determines the range of *BD_ADDRs* from $OUI|LAP_{start}$ 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 647FDA (*OUI*) and only the last 3 bytes are different for each device (*LAP*s), the filter range to include only these devices would be formatted as 647FDA|000000|FFFFFF. In other words, with this configuration, the ORCA will filter the discovered devices to include only those with MAC addresses from 647FDA000000 to 647FDAFFFFFF, inclusive.

If a range set to all 0s it is inactive, and all inactive ranges means basic reporting is enabled. Any non-zero values for a range configuration mean that range is active; filtered reporting is enabled.

With filtered reporting, after a scan is complete, the following steps are done:

1. The list of the discovered devices is filtered to include only those lying in one of the ranges defined in registers 0x 54 to 0x 57.
2. The last *N* devices detected are reported using the format described in §2.4, where *N* is defined by register 0x 50. One UL is reported for each enabled filter range. Only *LAP*s of

the devices followed by their RSSIs are reported in the filtered message, as the *OUI* is known. If no devices in an enabled filter range were discovered, an empty list is sent.

If a range is configured with $LAP_{start} > LAP_{end}$, it is active but empty (i.e.: an empty list is always reported with its corresponding header as shown in Figure 2-3).

If a range is configured with $LAP_{start} = LAP_{end}$, it only has one *BD_ADDR* in it (i.e.: the use-case where only a single BLE peripheral is of interest).

It is possible to have overlapping filter ranges. With this configuration, if a peripheral is discovered that falls in fore than one filter range, it is always reported under the first range that it falls into.

3.2.7.3 Example BLE Configuration DL Payloads

- Configure the ORCA to report only the last discovered BLE peripheral:
  - DL payload: **0x D0 01**
    - Register 0x 50 with bit 7 set to 1 = 0x D0
    - *N* = 1 and *R* = 0 = 0x 00 01
- Decrease the scan duty cycle to 50% while keeping scan durations the same to save battery life and read back to confirm:
  - DL payload: **0x D3 00 0F 53**
    - Register 0x 53 with bit 7 set to 1 = 0x D3
    - Scan window = 15 ms = 0x 00 0F
    - Register 0x 53 with bit 7 set to 0 = 0x D3
- Set filters to only report devices with MAC addresses ABCDEF000001 and ABCDEF500000 through ABCDEF999999:
  - DL payload: **0x D4 AB CD EF 00 00 01 00 00 01 D5 AB CD EF 50 00 00 99 99 99**
    - Register 0x 54 with bit 7 set to 1 = 0x D4
    - Filter range 0 = ABCDEF|000001|000001 = 0x AB CD EF 00 00 01 00 00 01
    - Register 0x 55 with bit 7 set to 1 = 0x D5
    - Filter range 1 = ABCDEF|500000|999999 = 0X AB CD EF 50 00 00 99 99 99

3.2.7.4 Guidelines on BLE Scan Configuration

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 ORCA 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 certain number of devices, a smaller DR would require more packets for the same number.

Moreover, due to LoRaWAN standard requirements, the packets cannot be sent out faster than about every 3 s [1].

Table 3-9 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 3-9, 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 3-9: Maximum Number of Reported BLE Devices per LoRaWAN Packet by Region (Basic/Filtered)

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 ORCA over time), it is recommended enough margin for the report time be considered between the scan duration and scan period.

3.2.8 MCU Temperature Threshold Configuration

The ORCA supports threshold-based reporting for the MCU temperature. Threshold-based reporting is a type of event-based reporting.

When the temperature thresholds are enabled, the ORCA reports the MCU temperature when it leaves the configured *threshold window*, and once again when the MCU temperature re-enters the threshold window (MCU temperature events). The threshold window is an open interval, meaning that even if the MCU temperature is equal to the *low threshold* or *high threshold*, the ORCA is considered to have left the threshold window.

When the MCU temperature is inside the threshold window, the ORCA is in the *idle* sampling state. When outside, the ORCA is in the *active* sampling state. This is illustrated using the default configuration in Figure 3-3.

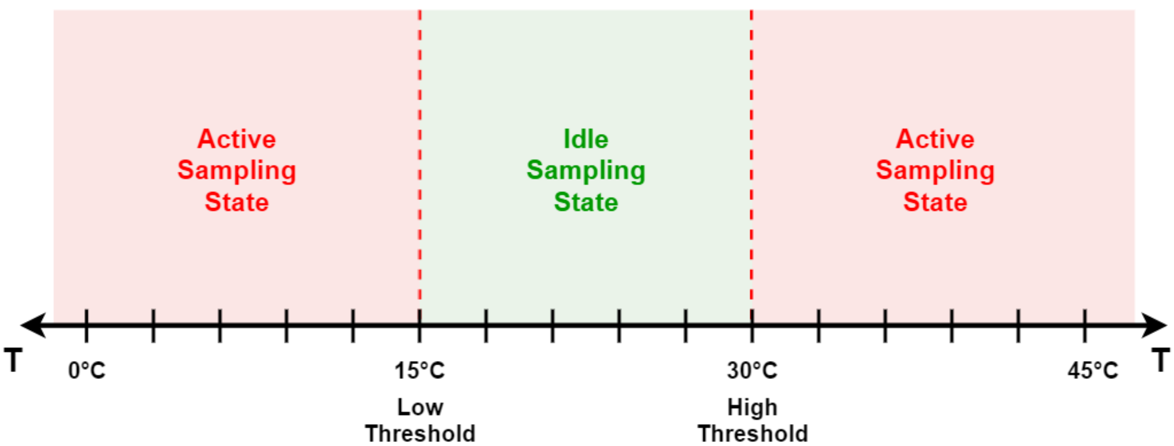

Figure 3-3: Default MCU Temperature Threshold Window

The threshold-based reporting is compatible with periodic reporting of the MCU temperature; both can be disabled and enabled independently[20].

Table 3-10 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.

[20] See §3.2.3 for details about periodic MCU temperature reporting configuration.

Table 3-10: MCU Temperature Threshold Configuration Registers

Address	Value	Size	Description	Default Value	JSON Variable (Type/Unit)
0x 60	Sample Period in Idle Sampling State	4 B	• Sample period of MCU temperature in s in idle sampling state • Acceptable values: 10, 11, 86400 • Other values: Invalid and ignored	300 s **0x 00 00 01 2C**	*temperature_sample_period_idle: <value>* *(unsigned/sec)*
0x 61	Sample Period in Active Sampling State	4 B	• Sample period of MCU temperature in s in active sampling state • Acceptable values: 10, 11, 86400 • Other values: Invalid and ignored	60 s **0x 00 00 00 3C**	*temperature_sample_period_active: <value>* *(unsigned/sec)*
0x 62	High/Low Thresholds	2 B	• Bits 8-15: High MCU temperature threshold (signed, 1°C/LSb) • Bits 0-7: Low MCU temperature threshold (signed, 1°C/LSb) • Acceptable values: -127 to 127 High threshold > low threshold	• High threshold = 30°C • Low threshold = 15°C **0x 1E 0F**	*temperature_thresholds {* *high: <value>,* *(signed/°C)* *low: <value>* *(signed/°C)* *}*
0x 63	Thresholds Enabled	1 B	• Bit 0: 0/1 = Thresholds disabled/enabled • Bits 1-7: Ignored	Disabled **0x 00**	*temperature_thresholds_enabled: <value>* *(unsigned/no unit)*

3.2.8.1 Sample Period in Idle/Active Sampling State

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

3.2.8.2 High/Low Threshold

MCU temperature thresholds are stored in a single 2-byte register, with the first byte storing the *high MCU temperature threshold*, and the last byte storing the *low MCU temperature threshold* with a 1°C precision. The high threshold must be greater than the low threshold.

3.2.8.3 Thresholds Enabled

The *thresholds enabled* register enables and disables the MCU temperature threshold-based reporting. When disabled, the thresholds and sample periods can still be configured.

3.2.8.4 Example MCU Temperature Threshold Configuration DL Payloads

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

3.2.9 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 3-11 shows the structure of the command and control registers. In this table, the bit indexing scheme is as shown in Figure 3-2.

Table 3-11: Command and Control Register

Address	Access	Name	Size	Description	JSON Variable (Type/Unit)
0x 70	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 ORCA • 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)* *}*
0x 71	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	*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)* *}*

Address	Access	Name	Size	Description	JSON Variable (Type/Unit)
0x 72	W	Reset to Factory Defaults	1 B	• Options: ○ 0x 0A = Reset App Configuration ○ 0x B0 = Reset LoRaMAC Configuration ○ 0x BA = Reset both App and LoRaMAC Configurations • Any other value: Invalid and ignored	*config_factory_reset {* *app_config: <value>, (unsigned/no unit)* *loramac_config: <value> (unsigned/no unit)* *}*

NOTE: The command and control Registers 0x 70 and 0x 71 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 the device to continually reboot.

3.2.9.1 Flash Write Command

Configuration changes are not retained after a power cycle unless they are saved in the flash memory. To save the ORCA's current configuration, a command is sent to write a value to the *Flash Write Command* register. This can be done in a DL payload at any time, including in the same payload as the other write commands.

Changes made to the LoRaMAC registers (0x 10 to 0x 15) must have bit 14 in the command set to 1 to be saved. Changes made to the application registers (0x 20 to 0x 63) must have bit 13 set to 1 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 ORCA will reset.

NOTE: If the command to reset was sent in a confirmed DL, the confirmation reply UL will not be sent. The ORCA will then rejoin the network, but the reset command will send again, causing a loop of continual rebooting. It is important to not send the reset command as a confirmed DL.

3.2.9.2 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 3-4, which is shown using the example FW v1.0.15.

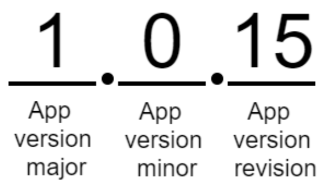

Figure 3-4: Example FW version format

Bits 8-31 in the *Metadata* register contain the LoRaMAC version numbers. The format is the same as shown in Figure 3-4. 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 ORCA are listed in Table 3-12.

Table 3-12: LoRaMAC Regions and Region Numbers

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

3.2.9.3 Reset to Factory Defaults

To reset all of the configuration register (0x 10 to 0x 63) values a write command must be sent to the r*eset configuration to factory defaults* register. The LoRaMAC configuration can be reset, the app config can be reset, or both can be reset.

3.2.9.4 Command and Control Examples

- Write current app configuration to flash
    - DL payload: **0x F0 20 00**
        - Register 0x 70 with bit 7 set to 1 = 0x F0
        - Bit 13 set to 1, all other bits set to 0 = 0x 20 00
- Write entire current configuration to flash
    - DL payload: **0x F0 60 00**

        - Register 0x 70 with bit 7 set to 1 = 0x F0
        - Bits 13 and 14 set to 1, all other bits set to 0 = 0x 60 00
- Reboot Device
    - DL payload: **0x F0 00 01**
        - Register 0x 70 with bit 7 set to 1 = 0x F0
        - Bit 0 set to 1, all other bits set to 0 = 0x 00 01
- Read metadata
    - DL payload = **0x 71**
        - Register 0x 71 with bit 7 set to 0 = 0x 71
- Reset entire configuration to factory default
    - DL payload: **0x F2 BA**
        - Register 0x 72 with bit 7 set to 1 = 0x 72
        - Reset app and LoRaMAC configuration = 0x BA

4 Appendix A: Default Values

Table 4-1: Default Values of Configuration Registers

Register 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	20	00 00 0E 10	Periodic Tx Configuration
Ticks per Battery	21	00 18	
Ticks per GNSS in STILLNESS State	22	00 01	
Ticks per GNSS in MOBILITY State	23	00 01	
Ticks per Accelerometer	24	00 00	
Ticks per BLE in DEFAULT State	25	00 01	
Ticks per BLE in STILLNESS State	26	00 00	
Ticks per BLE in MOBILITY State	27	00 00	
Ticks per Temperature	28	00 00	
Ticks per FSM State	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	
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	

Register Name	Reg. Address (Hex)	Default Value (Hex)	Section
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	51	01 03	
BLE Scan Interval	52	00 1E	
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	MCU 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 Specification," ver. 1.0.2, rev. B, Jul 2016.

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

[3] TEKTELIC Communications Inc., "KONA ATLAS," TEKTELIC Communications Inc., August 2023. [Online]. Available: https://www.atlas.tektelic.com/. [Accessed August 2023].

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