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eDoctor

Technical Reference Manual

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Revision History

Version	Date	Editor	Module Revision & FW Version	Comments
1.0	Nov 20, 2023	Shania Stewart, Tania Rizwan	Module Rev C FW v0.3.0	<ul style="list-style-type: none"> • Changed product name from Respiratory Sensor to eDoctor. • Added FW versions to document revision history and cover page. • Removed product family table and reformatted product code table to include module and PCBA T-codes. T-codes updated for current HW. • Improved the sensor's state machine and changed the method of entering and exiting battery saving mode. • Changed the name of Urgent Attention (UA) mode to Enhanced Reporting (ER) mode and use the term pulse rate (PR) instead of heart rate (HR). • Added images of the module with marked interfaces. • Updated the LED and push-button patterns and moved to their own section. • Added a port 12 UL payload format for the ER mode transition. • Replaced periodic port 100 metadata UL with periodic port 10 battery report UL. • Added information about the response to DL commands sent on port 101. • Minor changes to port 100 DL configuration registers 0x20 and 0x71. • Removed the port 100 DL configuration registers that were not carried over to the updated design. • Added port 100 DL configuration register 0x24. • Changed BT (body temperature) to ST (skin temperature) for clarity. • Removed mentions of rest mode and CSC from the document.
1.1	Dec 21, 2023	Shania Stewart	Module Rev C FW v0.3.0	<ul style="list-style-type: none"> • Changed decoding explanation of AF2 so that it uses units of <i>g</i>'s to match the data converter and the encoding explanation. • Fixed typo about the size of DL register 0x71. • Update to JSON string for DL register 0x72.

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Acronyms and Glossary

ABP	activation by personalization
ADR	adaptive data rate
AF	activity factor
App SW	application SW
B	byte
bpm	breath(s) per min, beat(s) per min
CE	chest expansion
DL	downlink
DR	data rate
EIRP	effective isotropically radiated power
ER	enhanced reporting
FEA	front-end application
flash	non-volatile memory of the MCU, containing the sensor configuration
FW	firmware
g	gravity (unit of acceleration $\approx 9.8 \text{ m/s}^2$)
ID	identity/identifier
IoT	Internet of things
JSON	JavaScript object notation
LED	light-emitting diode
LoRa	a patented “long-range” IoT technology acquired by Semtech
LoRAMAC	LoRaWAN MAC
LoRaWAN	LoRa wide area network (a network protocol based on LoRa)
LSb	least significant bit
MAC	medium access control
MCU	microcontroller unit
mg	milli- <i>g</i>
min	minute(s)
MSb	most significant bit
MSB	most significant byte
NA	North American
NS	network server
OTA	over-the-air
OTAA	OTA activation
POST	power-on self-test
PR	pulse rate
RAM	random-access memory
RF	radio frequency
RMS	root mean square
RO	read-only

RR respiratory rate
R/W read/write
Rx receiver
sec second(s)
SD standard deviation
ST skin temperature
SW software
transducer a sensing element in the eDoctor, such as the accelerometer
TRM technical reference manual (this document)
Tx transmitter
UL uplink
ver. version

1 Overview

IMPORTANT: Not all features described in this manual may be available on 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 the FW version of your device, send a command to query your device as described in Section 5.2.4.

This document describes the SW functionality, LoRa IoT UL (uplink) and DL (downlink) payloads, and configuration settings supported by the eDoctor, which is developed by TEKTELIC Communications Inc. This document assumes an understanding of the NS (network sensor) and its command interfaces. The eDoctor UL data are finally accessed and presented to the end user by a FEA (front-end application). The end user can also use the FEA to send DL commands to the eDoctor. This document also describes the interface between the eDoctor and the FEA.

The eDoctor is a light and small, battery powered LoRaWAN sensor that is worn around the chest (upper torso), and monitors and periodically reports several health signs of the person, including the ST (skin temperature), RR (respiratory rate), CE (chest expansion), activity status, position, and PR (pulse rate), which can assist with remote healthcare monitoring, as well as (early) detection of health conditions. The eDoctor also measures and periodically reports the remaining battery lifetime.

The eDoctor has a one red LED and one green LED, which show system activities or states, and two function buttons. It also has an adjustable strap for different chest sizes. The strap is supposed to be worn comfortably, but not too loosely, to prevent sagging. An easy rule of thumb is that the length of the unstretched strap should be 90% of the person’s chest size. The chest size should be measured at the time of exhalation using a tape measure.

Table 1-1 lists the eDoctor product codes for the different RF regions identified by the LoRa Alliance [1]—also see [1] for the Tx and Rx bands in each LoRaWAN region. As shown in Table 1-1, the different RF variants use the same HW; they are distinguished through different, specialized FW.

Table 1-1: eDoctor Order Codes per Region

Model Name	Product Code, Module-Level T-Code	Product Code, PCBA-Level T-Code	LoRaWAN RF Variant	Order Code
eDoctor	T0006955	T0008184	EU868	MEDBGEEU868
			US915	MEDBGEUS915
			AS923	MEDBGEAS923
			AU915	MEDBGEAU915

1.1 Information Streams

The UL and DL information streams supported by the SW have been summarized in Table 1-2.

Table 1-2: eDoctor Information Streams

Stream Direction	Data Type	Sent on LoRaWAN Port
UL (Sensor to NS)	Periodic Report of Battery and Health Signs	10
	Mode Transition Indicator	12
	Response to read commands from the NS	100
	Response to write commands from the NS	101
DL (NS to Sensor)	Change the Sensor Mode of Reporting	10
	Configuration and Control commands from the NS used to change the Sensor's behavior or inquire the Sensor for the values of configuration registers	100

1.2 eDoctor Battery Operation

The eDoctor is equipped with a replaceable CR2477 coin-cell battery with a nominal capacity of 1000 mAh. The eDoctor's estimated lifetime is at least 2 months in the **normal mode** with default configurations. An estimate for the remaining battery lifetime in percentage is included in every sensor report.

2 Operating Modes

2.1 Overview

The eDoctor checks to see if a user is wearing the device every minute and determines its operating mode based on the result. If the sensor determines that it is being worn, it will begin taking measurements and operate according to the current reporting mode configuration (normal reporting (NR) mode or enhanced reporting (ER) mode). If the sensor determines that it is not being worn, it will stop taking health measurements and enter battery saving mode to save power.

If the sensor is in NR mode, it will report measurements at a configurable interval (5 minutes by default). If the sensor is in ER mode, it will report measurements at a fixed interval of 1 minute. The uplink payload containing measurement data will indicate the sensor's current reporting mode. Users may configure the sensor to operate with the NR or ER mode configurations using either a downlink command or the appropriate push-button pattern, regardless of if the sensor is being worn or not.

If the sensor is in battery saving mode, it will only report the battery life at a configurable interval (12 hours by default).

2.2 Normal Reporting Mode

The eDoctor measures the **remaining battery lifetime**, **ST (skin temperature)**, **RR (respiratory rate)**, **CE (chest expansion)**, **AF (activity factor)**, **position (body angle)**, and **PR (pulse rate)**. The measuring and reporting pattern of the eDoctor in the **normal mode** is as follows:

1. **Remaining Battery Capacity:** Measured and reported every `norm_report_period` min.
2. **ST₁:** Measured and reported every `norm_report_period` min.
3. **RR:** Measured every min, an average is reported every `norm_report_period` min.
4. **CE:** Measured every min, an average is reported every `norm_report_period` min.
5. **AF₁:** Measured since last report, and reported every `norm_report_period` min.
6. **Position:** Measured and reported every `norm_report_period` min.
7. **PR:** Measured and reported every `norm_report_period` min.
8. **ST₂:** Measured and reported every `norm_report_period` min.
9. **AF₂:** Measured since last report, and reported every `norm_report_period` min.

`norm_report_period` is the normal mode report period (Section 5.2.2).

The **ST₁** and **ST₂** are the skin temperatures measured from the two thermistors. A function of these two, e.g., maximum, may be represented by the FEA as the actual skin temperature.

The **AF₁** is a boolean variable showing if the sensor user has been inactive or active since the last report. The state of having been active is when the sensor user has had at least a certain level of intensity in activity, as defined by `afl.intensity`, for at least a certain percentage of time, as defined by `afl.time_percentage`.

The **AF₂** is an indication for the intensity of the physical activity the person has had since the last report. This parameter equals the SD (standard deviation) of the magnitudes of the accelerometer samples taken since the last report. The FEA can map **AF₂** to three levels of physical activity, Low, Med, High, based on some predefined thresholds.

2.3 Enhanced Reporting Mode

The eDoctor goes into the **ER (enhanced reporting) mode** after observing a predefined function-button event, *or*, receiving a downlink command from the FEA to do so. The measuring and reporting pattern of the eDoctor in the ER mode is specified as:

1. **Remaining Battery Capacity:** Measured and reported every minute.
2. **ST₁:** Measured every min, an average is reported every minute.
3. **RR:** Measured every min, an average is reported every minute.
4. **CE:** Measured every min, an average is reported every minute.
5. **AF₁:** Measured since last report, and reported every minute.
6. **Position:** Measured and reported every minute.
7. **PR:** Measured and reported every minute.
8. **ST₂:** Measured every min, an average is reported every minute.
9. **AF₂:** Measured since last report, and reported every minute.

2.4 Battery Saving Mode

The eDoctor goes into battery saving mode if it detects that it is no longer being worn. The measuring and reporting pattern of the eDoctor in battery saving mode is specified as:

1. **Remaining Battery Capacity:** Measured and reported every `bsm_report_period` hour.

3 External Interfaces

The eDoctor's external interfaces are shown in Figure 3-1.

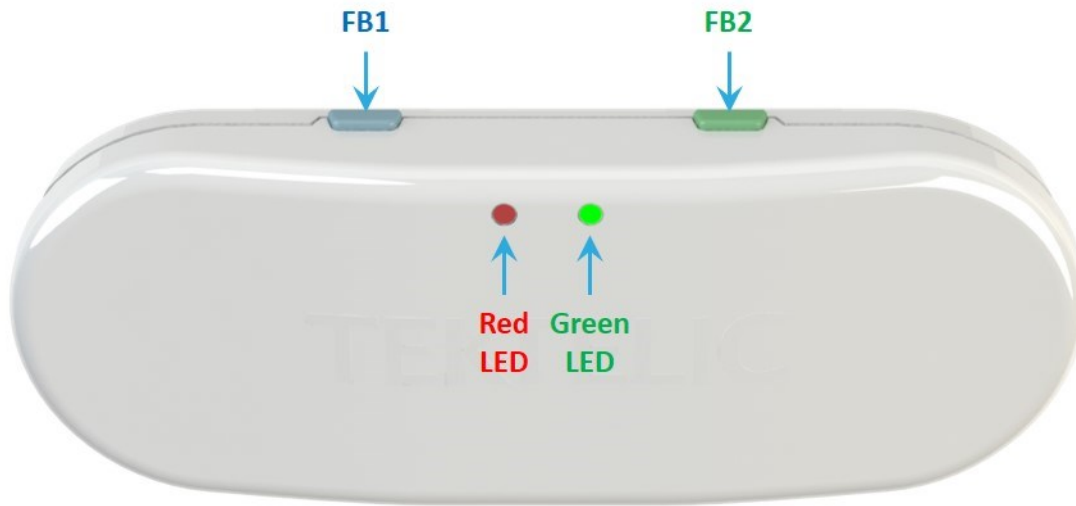


Figure 3-1: eDoctor Interfaces

3.1 LED Patterns

The eDoctor has two on-board LEDs: one **GREEN** and one **RED**. The LEDs are normally off. Their blinking patterns reflect different actions and states of the sensor. At a high level, the main patterns are summarized in Table 3-1. The detailed sequence and timings for each are described in the following subsections.

Table 3-1: Summary of eDoctor LED Patterns

LED Pattern	Meaning
RED blinking rapidly and single GREEN flash every 10s	JOIN mode; attempting to join the network
Short GREEN flash	UL sent
Long GREEN flash	DL received
Single RED flash	Enter ER mode
Single GREEN flash	Enter NR mode

3.1.1 Power-On and Network Join Patterns

When the sensor is activated or reset:

1. Both **GREEN** and **RED** are OFF for approximately 0.5 s after any reset occurs.
2. Upon startup, the SW conducts its POST. Both **GREEN** and **RED** are turned on when the POST begins.
3. When the POST ends (about 2 s), both **GREEN** and **RED** are turned off. Immediately following, the sensor will do 1 of 2 things, depending on the POST result:

- a) If the POST passes, **GREEN** is toggled ON and OFF 3 times, every 100 ms for 0.6 s, as shown in Figure 3-2. In this case, the LED pattern proceeds to step 4.
- b) If the POST fails, **RED** is toggled ON and OFF 3 times: every 100 ms for 0.6 s, as shown in Figure 3-2. In this case, the device restarts and the LED pattern begins again at step 1 after approximately 4 s.

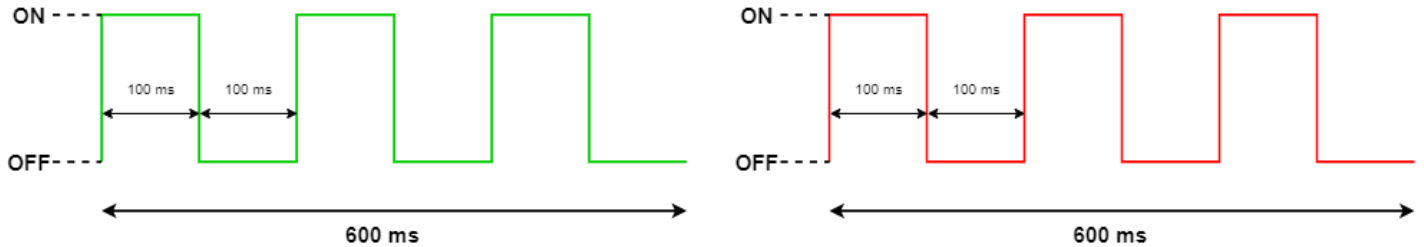


Figure 3-2: The GREEN POST Pass (left) and RED POST Failure (right) LED Patterns

- 4. After a successful POST, both **GREEN** and **RED** are turned off. Immediately following this, the sensor will enter JOIN mode and begin attempting to join the network. For the first hour:
 - a) **RED** is toggled ON and OFF every 50 ms.
 - b) **GREEN** flashes just once:
 - i. with a pulse duration of 25 ms right after transmitting a JOIN REQUEST. This occurs at approximately 10 s intervals at the beginning of the join process, but at decreasing regularity the longer the join process continues due to battery saving measures and possible duty-cycle limitations in certain regions [1].
 - ii. with a pulse duration of 100 ms right after receiving a JOIN ACCEPT. This will occur once, after which, the device will have joined the network and normal operation begins.

If the sensor has been unsuccessfully trying to join for more than an hour, it enters *join back-off* to conserve power. While the sensor still attempts to join, **RED** flashes ON and OFF twice, with each being 50ms, every 10 sec. The **GREEN** flashes with a pulse duration of 25 ms right after transmitting a JOIN REQUEST. The JOIN LED pattern is shown in Figure 3-3.

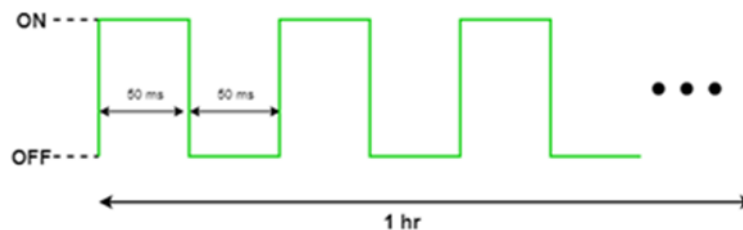


Figure 3-3: The LED Patterns During JOIN Mode

3.1.2 Normal Operation Patterns

After the Sensor has joined the network:

- a) **GREEN** flashes just once with a pulse duration of 25 ms right after transmitting an uplink.

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

3.2 Function Button Patterns

The eDoctor has two function buttons, **FB1** (blue) and **FB2** (green). Table 3-2 specifies function button patterns for different events. Additional details on each pattern are provided in the subsequent sections.

Table 3-2: eDoctor Function Button Patterns

Function	Function Button Pattern
Enter Enhanced Reporting (ER) Mode	<ul style="list-style-type: none">Press and hold either FB1 or FB2, not both, for more than 3 seconds before releasing to ensure that the device is in ER mode.The red/orange LED will flash for half a second to indicate the reporting mode configuration change to ER mode.An uplink will be sent on LoRaWAN port 12 to indicate the reporting mode configuration change. See Section 4.2 for more details.
Exit Enhanced Reporting (ER) Mode	<ul style="list-style-type: none">Press and release either FB1 or FB2, not both, 3 times within 3 seconds to ensure that the device is in NR mode.The green LED will flash for half a second to indicate the reporting mode configuration change to NR mode.
Restart Sensor	<ul style="list-style-type: none">Press and hold both FB1 and FB2 for at least 5 seconds before releasing.

3.2.1 Enter ER Mode

Pressing and holding **either FB1 or FB2, not both**, for more than 3 seconds before releasing will cause the sensor to enter ER mode if it was in NR mode prior to the pattern. The red/orange LED will flash once (ON for 500 ms) after the sensor has successfully recognized the “enter ER mode” button pattern, even if it was already in ER mode.

The button does not need to be released before the sensor will execute this function, and continuing to hold the button will not execute the function again. If one button is in the process of following the pattern, pressing and releasing the other button will immediately invalidate the current pattern. Both buttons must be released before the sensor will register a new pattern.

NOTE: The sensor may also send a UL on **LoRaWAN port 12** indicating the state change, along with a single flash of the **GREEN** LED. See Section 4.2 for more details on the sensor’s reporting mode change behavior caused by the button patterns.

3.2.2 Exit ER Mode

Pressing and releasing **either FB1 or FB2, not both**, 3 times within 3 seconds will cause the sensor to enter NR mode if it was in ER mode prior to the pattern. The green LED will flash once (ON for 500 ms) after the sensor has successfully recognized the “exit ER mode” button pattern, even if it was already in NR mode.

The user may press the button more than 3 times in the 3-second window and still execute the function once. The sensor will then apply a 2-second hold-off period after completing this function, where no button presses

will be registered as a new pattern during this period. If one button is in the process of following the pattern, pressing the other button during the 3-second window will immediately invalidate the current pattern. Both buttons must be released before the sensor will register a new pattern.

3.2.3 Restart Sensor

Pressing and holding **both FB1 and FB2** for at least 5 seconds will restart the sensor's MCU. The buttons do not need to be released before the sensor will execute this function. The user will be able to determine if the restart was successful using the LED pattern indicating the result of the POST check.

Since the proposed restart function is a SW feature, the sensor can only perform this function after the POST check is complete. The sensor will not restart again if a user continues to hold the buttons during the POST check, as the sensor does not initialize button and pattern detection until after the POST check.

4 UL Payload Formats

The UL streams (from the eDoctor to the NS) supported by the App SW are shown in Table 4-1, and are explained in Sections 4.1–4.3.

Table 4-1: UL Information Streams

Data Type	Sent on LoRaWAN Port
Periodic Report of Battery and Health Signs	10
Mode Transition Indicator	12
Response to Configuration and Control Commands	100/101

4.1 LoRaWAN Port 10: Periodic Report of Battery and Health Signs

For simplicity and power efficiency, a fixed and short payload format, as shown in Figure 4-1, is considered for the reports. The reports are sent on **LoRaWAN port 10**.

Battery Capacity 1 byte	ST ₁ 1 byte	RR 1 byte	ER bit RFU bit	CE 6 bits	RFU 1 byte	AF ₁ bit	Position 7 bits	HR 1 byte	ST ₂ 1 byte	AF ₂ 1 byte
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Figure 4-1: LoRaWAN Port 10 UL Payload Format

4.1.1 Encoding the UL

The eDoctor encodes the fields shown in Figure 4-1 into each UL sent on **LoRaWAN port 10** as follows:

1. The Battery Capacity byte is the remaining battery capacity, with 1 to 254 showing 1% to 100%. In fact, the remaining battery capacity of C in percentage is converted to $\left\lceil \frac{253}{99} (C - 1) + 1 \right\rceil$, where $\lceil \cdot \rceil$ is the round to the nearest integer function. If no measurement is available, the Battery Status byte is set to 0xFF.
2. The ST₁ byte is obtained as $\max ([20 \times (T_1 - 30)], 0)$, where $\lceil \cdot \rceil$ is the round to the nearest integer function, and where T_1 is the temperature measured from thermistor 1 in °C. Only measurements between 30°C and 42.7°C are reported. If no valid measurement is available, the ST₁ byte is set to 0xFF.
3. The RR byte is the measured RR in bpm (1 Lsb/bpm). Only measurements between 7 bpm and 60 bpm are reported. If no measurement is available, the RR byte is set to 0xFF.
4. The status of the ER mode is encoded in the ER Bit (0/1 = mode inactive/active). A 0 indicates the normal reporting mode.
5. The 6-bit CE is the measured CE in percentage (1 Lsb/0.2%), clipped from above at 12%. If no measurement is available, the 6-bit CE is set to 0x3F.
6. The AF₁ bit shows the activity status since the last report. If no measurement is available, the AF₁ bit is set to 0 (which can also be interpreted as “being inactive”).
7. The 7-bit Position is an unsigned angle from 0° to 90°, with 0° corresponding to the sensor user lying down. If no measurement is available, the 7-bit Position is set to 0x7F.

8. The PR byte is the measured PR in bpm. Only measurements between 50 bpm and 200 bpm are reported. If no measurement is available, the PR byte is set to 0xFF.
9. The ST₂ byte is obtained as $\max([20 \times (T_2 - 30)], 0)$, where $[\cdot]$ is the round to the nearest integer function, and where T_2 is the temperature measured from thermistor 2 in °C. Only measurements between 30°C and 42.7°C are reported. If no valid measurement is available, the ST₂ byte is set to 0xFF.
10. The AF₂ byte shows the intensity of the physical activity since the last report (1 LSB/0.01 g), clipped from above at 2.5 g. If no measurement is available, the AF₂ byte is set to 0xFF.

If the sensor is in battery saving mode, then it will periodically report the remaining battery capacity and set all other bytes in the UL to 0xFF.

Table 4-2 shows a summary of the UL payload fields.

Table 4-2: UL Payload Fields

Field	Size	Data Format	JSON Variable (Type, Unit)
Battery Status	1 B	<ul style="list-style-type: none"> • = $\left\lceil \frac{253}{99} (C - 1) + 1 \right\rceil$, C = remaining battery capacity in % • = 255 if no measurement available 	remaining_battery_capacity (unsigned, %)
ST ₁	1 B	<ul style="list-style-type: none"> • = $\max([20 \times (T_1 - 30)], 0)$, T_1 = Skin temperature from thermistor 1 in °C • = 255 if no valid T_1 available 	bt1 (unsigned, °C)
RR	1 B	<ul style="list-style-type: none"> • = RR in bpm • = 255 if no RR is available 	rr (unsigned, bpm)
ER Mode Status	1 b	<ul style="list-style-type: none"> • 0 = ER mode inactive • 1 = ER mode active 	er (unsigned, no unit)
CE	6 b	<ul style="list-style-type: none"> • = $[5 \times \min(CE, 12)]$, CE = chest expansion in % • = 63 if no valid CE available 	ce (unsigned, %)
AF ₁	1 b	<ul style="list-style-type: none"> • = 0 if inactive, or if no measurement available • = 1 if active 	af1 (unsigned, no unit)
Position	7 b	<ul style="list-style-type: none"> • = Position in ° (deg) • = 127 if no position available 	position (unsigned, °)
PR	1 B	<ul style="list-style-type: none"> • = PR in bpm • = 255 if no PR available 	hr (unsigned, bpm)
ST ₂	1 B	<ul style="list-style-type: none"> • = $\max([20 \times (T_2 - 30)], 0)$, T_2 = Skin temperature from thermistor 2 in °C • = 255 if no valid T_2 available 	bt2 (unsigned, °C)
AF ₂	1 B	<ul style="list-style-type: none"> • = $[100 \times \min(A, 2.5)]$, A = Activity intensity in g • = 255 if no A available 	af2 (unsigned, g)

Example: Normal mode of reporting, remaining battery capacity = 92%, ST from thermistor 1 = 37.216°C, RR = 12 bpm, CE = 1%, BV = 3.0 V, active status, position = 85°, PR = 72 bpm, ST from thermistor 2 = 36.941°C, activity intensity = 0.253 g is encoded as 0x EA 90 0C 05 64 D5 48 8B 19.

4.1.2 Decoding the UL

Decoding the UL (how the received uplink is decoded): Considering Figure 4-1, the following is how the received uplink *sent on LoRaWAN port 10* is decoded:

1. The remaining battery capacity in percentage is obtained as $\left\lceil \frac{99}{253} (B - 1) + 1 \right\rceil$, where B is the unsigned integer value of the “Battery Status” byte, and where $\lceil . \rceil$ is the round to the nearest integer function. A value of $B = 255$ means no valid battery status is available.
2. The ST_1 in °C, with two decimal digits, is obtained as $t/20 + 30$, where t is the unsigned integer value of the 8-bit ST_1 . A value of $t = 255$ means no valid ST_1 is available.
3. The RR in bpm is obtained as the unsigned integer value of the 8-bit RR. A value of 255 means no valid RR is available.
4. The ER Bit shows the ER mode status: 0/1 = mode inactive/active. ER Bit equal to 0 indicates the normal mode.
5. The CE in percentage is obtained as the unsigned integer value of the 6-bit CE divided by 5. A value of 63 means no valid CE is available.
6. The AF_1 (flag) since the last report is shown by the AF_1 bit: 0/1 = Activity not detected/detected.
7. The body position in degrees is obtained as the unsigned integer value of the 7-bit Position. A value of 127 means no valid body position is available.
8. The PR in bpm is obtained as the unsigned integer value of the 8-bit PR. A value of 255 means no valid PR is available.
9. The ST_2 in °C, with two decimal digits, is obtained as $t_2/20 + 30$, where t_2 is the unsigned integer value of the 8-bit ST_2 . A value of $t_2 = 255$ means no valid ST_2 is available.
10. The physical activity intensity in g is obtained as $0.01 \times AF_2$, where AF_2 is the unsigned integer value of the 8-bit AF_2 . A value of $AF_2 = 255$ means no AF_2 is available.

Example: Base64 tp8PI2QIN6AD or hex B6 9F 0F 97 64 08 37 A0 03 is decoded as ER mode of reporting, remaining battery capacity = 72%, ST from thermistor 1 = 37.95°C, RR = 15 bpm, CE = 4.6%, BV = 3.0 V, inactive status, position = 8°, PR = 55 bpm, ST from thermistor 2 = 38.00°C, activity intensity = 0.03 g.

If the sensor is in battery saving mode, then it will periodically report the remaining battery capacity and set all other bytes in the UL to 0xFF.

4.2 LoRaWAN Port 12: Mode Transition Indicator

The mode transition UL sent on *LoRaWAN port 12* includes a 1-byte value with the following meaning:

- Enter ER mode configuration: 0x 01

The eDoctor will send a mode transition UL to indicate when the eDoctor reporting mode configuration changes from normal reporting mode to enhanced reporting mode when **all** the following conditions are met:

- The sensor was in NR mode at the start of the current (60-second) measurement period
- The push button pattern for ER mode is performed for the *first time* in the current measurement period

This prevents the sensor from sending many mode transition ULs in a short of period of time. If users execute the enter/exit ER mode push-buttons patterns multiple times within a measurement period, the last pattern performed determines the sensor's reporting mode configuration.

4.3 LoRaWAN Port 100 & 101: Response to Configuration and Control Commands

The eDoctor responses to DL configuration and control commands (which are **sent on LoRaWAN port 100**) are sent in the UL on **LoRaWAN port 100** and/or **LoRaWAN port 101**. These responses include the following:

- Returning the value of (a) configuration register(s) in response to an inquiry from the NS.
- Writing to (a) configuration register(s).

In the first case, the Sensor responds with the address and value of each of the registers under inquiry on **LoRaWAN port 100**. The response can be in one or more consecutive UL packets depending on the maximum frame payload size allowed.

In the second case, the Sensor responds by immediately sending the last byte of the LoRaWAN DL frame counter value followed by a size byte indicating the number of registers that were **NOT** successfully written to, and then the addresses of the failed registers on **LoRaWAN port 101**. The intent is to both inform the user which set of commands the end-device is referring to, and which (if any) of the write commands were seen as invalid. As a result, if a redundant write command is issued (i.e., the value of that register is not changing), then the Sensor will not report its address, because it was not an invalid command. In the case where all the write commands are performed successfully, the Sensor will send back a frame with only the last byte of the DL frame counter value and a size indication byte of "00" on **LoRaWAN port 101**.

If the DL payload also has read commands, the address and value of each of the registers under inquiry are reported separately on **LoRaWAN port 100**. In this case, the UL response to read commands on **LoRaWAN port 100** is handled before the UL response to write commands on **LoRaWAN port 101**.

5 DL Payload Formats

The DL streams (from the NS to the eDoctor) supported by the App SW are shown in Table 5-1, and are explained in Sections 5.1 and 5.2.

Table 5-1: DL Information Streams

Data Type	Sent on LoRaWAN Port
Reporting Mode Configuration Commands	10
Configuration and Control Commands	100

5.1 LoRaWAN Port 10: Reporting Mode Configuration Commands

There are DL commands sent to the sensor that instructs the sensor to go to the normal reporting mode or enhanced reporting mode. These commands are sent on **LoRaWAN port 10**:

1. Go to normal reporting mode: 0x 00 01 00
2. Go to enhanced reporting mode: 0x 00 01 FF

5.2 LoRaWAN Port 100: Configuration and Control Commands

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 5-1. A big-endian format (MSB and MSb first) is always followed.

The Register Address is used to access various configuration parameters. These addresses are bound between 0x00 and 0x7F.

Bit 7 of the first byte determines whether a read or write action is being performed, as shown in Figure 5-1. All read commands are one-byte long. Data following a read access command will be interpreted as a new command block. Read commands are processed last. For example, in a single DL message, if there is a read command from a register and a write command to the same register, the write command is executed first.

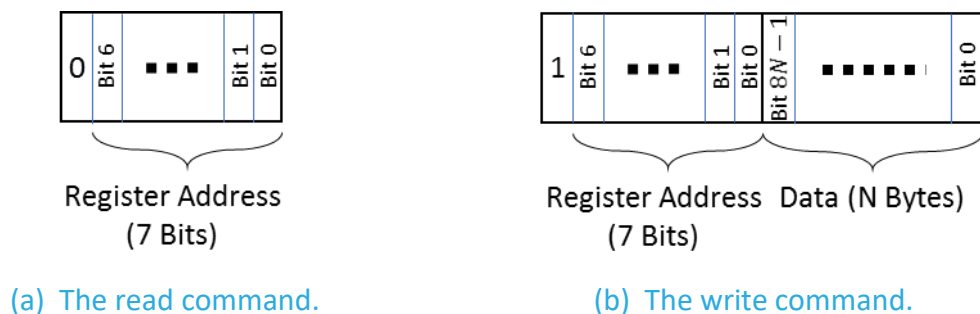


Figure 5-1: The format of a DL configuration and control message block.

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

When a write command is sent to the Sensor, the Sensor immediately responds by sending a UL containing the last byte of the LoRaWAN DL frame counter value followed by a size byte indicating the number of

appended addresses, and the addresses of the registers that were not successfully written to on **LoRaWAN port 101** (see Section 4.3).

DL Configuration and Control Commands fall into one of the following categories and are discussed in Sections 5.2.1 to 5.2.4:

- LoRaMAC Configuration
- Periodic Tx Configuration
- AF Configuration
- Command and Control

5.2.1 LoRaMAC Configuration

LoRaMAC options can be configured using DL commands. These configuration options change the default MAC configuration that the eDoctor loads on start-up. They can also change certain run-time parameters. Table 5-2 shows the LoRaMAC configuration registers. All the registers have R/W (read/write) access. In this table, the bit indexing scheme is as shown in Figure 5-1.

Table 5-2: LoRaMAC Configuration Registers

Address	Value	Size	Description	JSON Variable (Type, Unit)	Default Value
0x10	Join Mode	2 B	<ul style="list-style-type: none"> • Bit 15: 0/1 = ABP/OTAA mode • Bits 0-14: Ignored 	loramac_join_mode: <value> (unsigned, no unit)	0x 80 00
0x11	Options	2 B	<ul style="list-style-type: none"> • Bit 0: 0/1 = Unconfirmed/Confirmed UL • Bit 1 = 1 (read-only): 0/1 = Private/Public Sync Word • Bit 2: 0/1 = Disable/Enable Duty Cycle • Bit 3: 0/1 = Disable/Enable ADR • Bits 4-15: Ignored 	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 00 0E
0x12	DR and Tx Power ¹	2 B	<ul style="list-style-type: none"> • Bits 8-11: Default DR number • Bits 0-3: Default Tx power number • Bits 4-7, 12-15: Ignored 	loramac_dr_tx { dr_number: <value>, (unsigned, no unit) tx_power_number: <value> (unsigned, no unit) }	0x 00 00 (Tx Power 0 means max power, as per Table 5-3)

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

0x13	Rx2 Window	5 B	<ul style="list-style-type: none"> • Bits 8-39: Channel frequency in Hz for Rx2 • Bits 0-7: DR for Rx2 	<pre>loramac_rx2 { frequency: <value>, (unsigned, Hz) dr_number: <value> (unsigned, no unit) }</pre>	As per Table 5-4
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Note: Modifying these values only changes them in the eDoctor. Options for the eDoctor in the NS also need to be changed in order to not strand an eDoctor. Modifying configuration parameters in the NS is outside the scope of this document.

Table 5-3: Default Maximum Tx Power in Different Regions

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

Table 5-4: Default Values of Rx2 Channel Frequency and DR Number in Different Regions

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

Examples:

- Enable ADR, disable Duty Cycle, make UL confirmed:
 - DL payload: 0x 91 00 0B
- Set default DR number to 3, default Tx power number to 4:
 - DL payload: 0x 92 03 04

5.2.2 Periodic Tx Configuration

Table 5-5 shows the configuration registers for the eDoctor periodic Tx operation. This includes periodic transmissions in the normal mode and battery saving mode. All registers have R/W access.

Table 5-5: Periodic Tx Configuration Registers

Address	Name	Size	Description	JSON Variable (Type, Unit)	Default Value
0x20	Normal Mode Report Period	1 B	<ul style="list-style-type: none"> Report period in the normal mode (1 min/LSb) Acceptable values: 2-60 Other values: Invalid and ignored 	norm_report_period: <value> (unsigned, min)	0x 05 (5 minutes)
0x24	Battery Saving Mode Report Period	1 B	<ul style="list-style-type: none"> Report period of battery level in battery saving mode (1 hour/LSb) Acceptable values: 1-168 Other values: Invalid and ignored 	bsm_report_period: <value> (unsigned, hour)	0x 0C (12 hours)

5.2.3 AF (Activity Factor) Configuration

The activity status, AF₁, of the sensor user since the last report is defined as either “inactive” or “active”, based on lacking or having certain amount of activity for at least a percentage of time. The amount of activity is represented by the SD of the magnitudes of the acceleration samples collected over intervals of 12 sec. If the SD is “<” or “≥” `af1.intensity` in an interval of 12 sec, the sensor user is considered inactive or active in that interval. The sensor user is considered inactive or active since the last report if the active time accumulated since the last report is “<” or “≥” certain percentage of the time, `af1.time_percentage`, since the last report. For example, if `af1.time_percentage` is 40%, and the report period is 1 min, the sensor user is declared “Active” in the report only if the sensor user has been active for at least two 12-sec intervals over the past min.

Another indication for the physical activity intensity is AF₂, which is calculated and included in the frame payload as follows. AF₂ is the RMS (root mean square) of the above mentioned SDs calculated over all 12-sec intervals since the last report. AF₂ has the unit of *g*, and is reported with the precision 0.01 *g*/LSb or 10 mg/LSb in the payload.

Table 5-6 shows the AF configuration register. This register has R/W access. In this table, the bit indexing scheme is as shown in Figure 5-1.

Table 5-6: AF Configuration Register

Address	Name	Size	Description	JSON Variable (Type, Unit)	Default Value
0x4A	AF ₁ Parameters	1 B	<ul style="list-style-type: none"> Bits 0-3 (Intensity) Unsigned, 0.1 <i>g</i>/LSb Bits 4-7 (Time Percentage) Unsigned, 10%/LSb Values 11-15: Invalid and ignored 	<pre>af1 { intensity: <value>, (unsigned, g) time_percentage: <value></pre>	0x 32

				(unsigned, no unit) }	
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5.2.4 Command and Control

Configuration changes are not retained after a power cycle unless they are saved in the flash memory. Table 5-7 shows the structure of the Command-and-Control registers. In this table, the bit indexing scheme is as shown in Figure 5-1.

Table 5-7: Command-and-Control Registers

Address	Access	Name	Size	Description	JSON Variable (Type, Unit)
0x70	W	Flash Write Command	2 B	<ul style="list-style-type: none"> • Bit 14: <ul style="list-style-type: none"> • 0/1 = Do not write/Write LoRaMAC Configuration • Bit 13: <ul style="list-style-type: none"> • 0/1 = Do not write/Write App SW Configuration • Bit 0: <ul style="list-style-type: none"> • 0/1 = Do not restart/Restart Tracker • Bits 1-12, 15: Ignored 	<pre>write_to_flash { app_config: <value>, (unsigned, no unit) lora_config: <value>, (unsigned, no unit) restart_sensor: <value> (unsigned, no unit) }</pre>
0x71	R	FW Version	7 B	<ul style="list-style-type: none"> • Bits 48-55: App version major • Bits 40-47: App version minor • Bits 32-39: App version revision • Bits 24-31: LoRaMAC version major • Bits 16-23: LoRaMAC version minor • Bits 8-15: LoRaMAC version revision • Bits 0-7: LoRaWAN region number (see Section 5.2.4.1) 	<pre>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) lorawan_region: <value> (unsigned, no unit) }</pre>

0x72	W	Reset Configuration Registers to Factory Defaults ²	1 B	<ul style="list-style-type: none"> • 0x0A = Reset App SW Configuration • 0xB0 = Reset LoRaMAC Configuration • 0xBA = Reset both App SW and LoRaMAC Configurations • Any other value: Invalid and ignored 	configuration_factory_reset: <value>, (unsigned, no unit)
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Note: The Command and Control registers are always executed after the full DL configuration message has been decoded. The reset commands should always be sent as an unconfirmed DL message. Failure to do so may cause a poorly designed NS to continually reboot the eDoctor.

5.2.4.1 LoRaWAN Region

The LoRaWAN region number is the last byte of the Metadata register (Register 0x71). Current LoRaWAN regions and corresponding region numbers for the eDoctor are listed in Table 5-8.

Table 5-8: LoRaWAN Regions and Region Numbers

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

Examples:

- Write the App SW configuration to the flash
 - DL payload: 0x **F0** 20 00
- Write the App SW and LoRaMAC configurations to the flash
 - DL payload: 0x **F0** 60 00
- Reboot the sensor
 - DL payload: 0x **F0** 00 01
- Get the FW version and reset the App configuration to factory defaults
 - DL payload: 0x **71 F2** 0A

² After sending the reset-to-factory-defaults command, the sensor is automatically reset with corresponding default configuration values.

6 eDoctor and FEA Interface

6.1 UL Direction

This includes the following:

1. Periodic reports of the battery and health signs on **LoRaWAN port 10**. The format of these reports and their decoding have been fully explained in Section 4.1.

6.2 DL Direction

The DL direction includes the configuration and control commands sent from the FEA to the sensor. As the sensor is a LoRaWAN Class A end device, these commands are only received by the sensor shortly after it sends an uplink. These configuration and control commands includes the following:

1. Control command to change the sensor mode of reporting, sent on **LoRaWAN port 10**. The use and format of this command has been specified in Section 5.1.
2. Configuration and control commands sent on **LoRaWAN port 100** to,
 - a. change the configuration of the sensor
 - b. save the current sensor configuration to its flash
 - c. simply reboot the sensor, or, reboot the sensor to its factory defaults.

References

- [1] LoRa Alliance, "LoRaWAN Regional Parameters," ver. 1.0.2, rev. B, Feb 2017.
- [2] LoRa Alliance, "LoRaWAN Specification," ver. 1.0.2, Jul 2016.