Beacon Firmware Usage Guide

Device: Vitalacy Beacon revD **SoC:** Nordic Semiconductor nRF52833 (ARM Cortex-M4) **Firmware Version:** 2.2.0 **RF Technology:** Bluetooth Low Energy (BLE)

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1. Operating Modes

The beacon operates in one of two mutually exclusive RF modes, selected by the `in_passive` configuration parameter.

1.1 Active Mode (Advertising)

Active mode is the default operating mode (`in_passive = false`). In this mode the beacon continuously transmits BLE advertising packets to be detected by scanning devices (e.g. badges and wristbands in the same environment).

RF Transmission Characteristics:

Parameter	Value
Advertising channels	37, 38, 39 (2402, 2426, 2480 MHz)
Advertisement interval	25 ms
TX power	0–40 dBm, configurable (default 30 dBm)
TX power control	External RF attenuator IC, 6-bit serial control

Packet Types:

The packet transmitted depends on the beacon type and whether zones are configured:

Beacon Type	Zones Disabled	Zones Enabled
Room (`bcn_type = 1`)	`beacon_room_packet`	`beacon_zone_room_packet`
Hall (`bcn_type = 0`)	`beacon_hall_packet`	`beacon_zone_hall_packet`

Advertising on individual channels can be selectively disabled via `adv_ch_37_disable`, `adv_ch_38_disable`, and `adv_ch_39_disable` configuration parameters.

When a remote device connects to the beacon, advertising is paused for the duration of the connection. BLE connection parameters during a connection: minimum interval 180 units, maximum interval 240 units, latency 4.

TX Power Control Hardware: TX power is set by a hardware RF attenuator IC using a serial GPIO bit-bang protocol. This gives precise, hardware-controlled output power independent of the BLE stack's own TX power setting.

1.2 Passive Mode (Scanning and Connecting)

Passive mode is enabled by setting `in_passive = true`. In this mode the beacon stops advertising and instead scans for BLE packets from Vitalacy-compatible devices (badges/wristbands). When a device is detected at sufficient signal strength, the beacon initiates a brief BLE connection to exchange location data.

Scanning Characteristics:

Parameter	Value
Scan interval	500 ms
Scan window	55 ms
Target packets	Vitalacy manufacturer-specific data (`pkt_id_passive`)

Detection Algorithm:

The beacon tracks up to 15 devices simultaneously within a configurable detection window (default 3000 ms). For each device, it accumulates RSSI samples and applies two parallel threshold checks:

1. **Average RSSI check** — initiates connection if:
    - Mean RSSI over collected packets ≥ `rssi_thresh` (default −74 dBm), AND
    - Packet count ≥ `packet_thresh` (default 8 packets)
2. **Moving average check** — initiates connection if:
    - N-packet moving average RSSI ≥ `mvg_avg_rssi_thresh` (default −69 dBm), AND
    - Packet count ≥ `mvg_avg_num_pkts_thresh` (default 2 packets)

Either condition passing is sufficient to trigger a connection attempt. A device whose threshold was previously passed will always be connected to on subsequent packets within the same window.

On Connection:

The beacon performs a GATT write of 2 bytes `[beacon_data_id, (int8_t)rssi_average]` to the badge's characteristic handle, then immediately disconnects. After disconnect, normal scanning resumes. The connection is short-lived and solely used to deliver the RSSI reading.

1.3 Mode Transitions

Mode is controlled by `in_passive`. The radio is reconfigured whenever:

- A configuration update changes `in_passive`
- A BLE connection state changes (connected/disconnected)
- A heartbeat period begins or ends

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2. Configuration System

2.1 Storage

Configuration parameters are stored in Non-Volatile Storage (NVS) in a dedicated flash partition.

Parameters persist across power cycles and firmware updates. On first boot (or after a schema version change), parameters are initialised to their defaults. Any parameter change triggers a `config_event` that is broadcast to all subsystems — radio, attenuator, heartbeat, and zones — which each re-read the relevant parameters and apply the change immediately.

2.2 Parameters

The beacon has 18 configurable parameters. Parameters are identified by an integer ID and stored with their declared type.

General Parameters

ID	Name	Type	Default	Range	Description
0	`tx_pwr`	U8	30	0–40	RF TX power in dBm. Stored as a positive integer; the attenuator driver negates it internally. Controls active-mode advertising and zone packet output power. Does not affect heartbeat TX power.
1	`bcn_type`	U8	1 (Room)	0 = Hall, 1 = Room	Selects which advertising packet template to use in active mode. Also reported in the heartbeat packet.
2	`hb_int_min`	U16	60	0–720	Heartbeat interval in minutes. See Section 3.
3	`hb_dur_s`	U8	3	0–30	Duration in seconds for which the heartbeat advertisement is transmitted each interval.
4	`in_setup`	BOOL	false	—	When true, the beacon advertises a setup packet instead of the normal beacon packet. Used during factory provisioning.

Passive Mode Parameters

ID	Name	Type	Default	Range	Description
5	`in_passive`	BOOL	false	—	Switches the beacon between active (advertising) and passive (scanning) mode.

ID	Name	Type	Default	Range	Description
6	`rssi_thresh`	U8	74	20–100	Average RSSI threshold for connection decisions. Stored as a positive integer; evaluated internally as a negative dBm value (e.g. 74 → –74 dBm).
7	`packet_thresh`	U8	8	—	Minimum number of packets that must be received from a badge before the average RSSI check is applied.
8	`detection_window`	U32	3000	—	Duration in milliseconds over which badge packet data is collected and evaluated.
9	`mvg_avg_rssi_thresh`	U8	69	0–255	Moving average RSSI threshold. Stored as a positive integer; evaluated as negative dBm (e.g. 69 → –69 dBm).
10	`mvg_avg_num_pkts`	U8	2	—	Number of most-recent packets included in the moving average RSSI calculation.
11	`mvg_avg_num_pkts_thresh`	U8	2	—	Minimum number of packets collected before the moving average check is evaluated.

Advertising Channel Parameters

ID	Name	Type	Default	Description
12	`adv_ch_37_disable`	BOOL	false	Disable BLE advertising channel 37 (2402 MHz).
13	`adv_ch_38_disable`	BOOL	false	Disable BLE advertising channel 38 (2426 MHz).
14	`adv_ch_39_disable`	BOOL	false	Disable BLE advertising channel 39 (2480 MHz).

Zone Parameters

Zones enable a beacon to transmit custom data payloads associated with a defined location zone. Zones are active when `zone_id ≠ 0` or `zone_type ≠ 0`.

ID	Name	Type	Default	Description
15	`zone_id`	U32	0	Unique zone identifier. 0 = no zone (standard operation).
16	`zone_type`	U8	0	Zone type classification. 0 = no zone.

ID	Name	Type	Default	Description
17	`zone_data`	STRING	`""`	Up to 16 bytes of zone-specific data encoded as a hex string, included in zone advertisement packets.

3. Heartbeat

The heartbeat is a periodic BLE advertisement that transmits a compact status payload. It allows the infrastructure to remotely monitor each beacon's health, battery state, firmware version, and operating mode without requiring a connection.

3.1 Timing

Property	Value	Configurable
Interval	60 minutes	Yes (`hb_int_min`, range 0–720 min)
Advertisement duration	3 seconds	Yes (`hb_dur_s`, range 0–30 s)
Advertisement interval	30 ms	No
TX power	8 dBm	No (fixed, independent of `tx_pwr`)
First heartbeat	Immediately on boot	No (`CONFIG_HEARTBEAT_ON_BOOT=y`)

3.2 Behaviour

- The heartbeat timer starts at boot. The first heartbeat fires immediately (boot heartbeat), then repeats every `hb_int_min` minutes.
- If the device is mid-connection when the heartbeat is due, the heartbeat is deferred and retried every 100 ms until either the connection ends or the heartbeat timeout is reached. If the timeout is exceeded, the heartbeat for that interval is skipped.
- When an incoming (non-self-initiated) connection is made and then disconnects, a forced heartbeat is triggered after a 5-second delay. This ensures the infrastructure receives up-to-date status after an unexpected disconnect.
- During the heartbeat advertisement, all other radio activity (advertising or scanning) is paused. Normal operation resumes immediately after the heartbeat duration elapses.

3.3 Packet Format

The heartbeat packet is 10 bytes (`pkt_id_heartbeat`), transmitted as BLE manufacturer-specific advertising data:

Byte	Field	Description
0	TX Power	Current TX power setting in dBm (from `tx_pwr` parameter)
1–2	Battery Voltage	VDD rail voltage in millivolts, little-endian. See Section 4 for how this is derived.

Byte	Field	Description
3	Battery Bank	Current active battery bank, 1-indexed (1–4). 0 if bank rotation has not yet started.
4	FW Version Major	Firmware version major digit
5	FW Version Minor	Firmware version minor digit
6	FW Version Patch	Firmware version patch digit
7	Passive Mode	1 if beacon is in passive mode, 0 if in active mode
8	Beacon Type	0 = Hall, 1 = Room
9	Reserved	Fixed value 0x11

4. Battery Bank System

The beacon is designed for long-term deployment using a multi-bank primary battery architecture. Four independent battery banks are managed by the firmware to extend operational lifetime, with automatic rotation when a bank is depleted.

4.1 Hardware Architecture

Each bank is independently switched via its GPIO control pin. At startup all control pins are driven HIGH (all banks disabled); the firmware enables individual banks only as needed during rotation.

4.3 Bank Rotation Logic

The depletion threshold is **2300 mV** (2.3 V).

4.4 Voltage Reporting in Heartbeat

Battery state is included in every heartbeat packet (bytes 1–3):

- **Bytes 1–2:** Voltage in millivolts as described above.
- **Byte 3:** Active bank number (1–4), or 0 if rotation has not started.

This allows the infrastructure to track individual bank exhaustion events and plan battery maintenance without physical inspection of the device.

Appendix: Source File Reference

File	Role
src/main.c	Application entry point; heartbeat packet encoding
src/core/radio/radio.c	Mode control; passive detection state machine

File	Role
src/core/attenuator.c	RF TX power attenuator control
src/core/battery/bank.c	Battery bank rotation and voltage measurement
src/core/battery/battery.c	Battery monitoring thread (1-hour poll)
src/subsys/config/params.c	All 18 parameter definitions with types, ranges, and defaults
lib/zephyr_common/subsys/heartbeat/heartbeat.c	Heartbeat timer, advertising, and deferral logic
config/prj.conf	Zephyr build-time configuration (scan intervals, connection params, etc.)