Tire Pressure Monitoring System Profile

Bluetooth® Profile Specification

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Abstract:

This profile enables a client to monitor real-time data from one or more Tire Pressure Monitoring System (TPMS) Sensors in a TPMS by receiving TPMS Sensor data sent in advertisements, without requiring a connection to be established. The client role, called the Monitor, may connect to a TPMS Sensor to access characteristics that contain TPMS data and to perform configuration tasks.

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Contents

1 Introduction

The Tire Pressure Monitoring System (TPMS) Profile is used to enable a data collection device, called a Monitor, to obtain data from one or more Tire Pressure Monitoring System (TPMS) Sensors that expose the Tire Pressure Monitoring System Service (TPMS Service) [1].

1.1 Language

1.1.1 Language conventions

In the development of a specification, the Bluetooth SIG has established the following conventions for use of the terms “shall”, “mandatory”, “shall not”, “should”, “should not”, “may”, “optional”, “must”, and “can”. In this Bluetooth specification the terms in Table 1.1 have the specific meanings given in that table, irrespective of other meanings that exist.

Term	Definition
shall *or* mandatory	—used to express what is required by the specification and is to be implemented exactly as written without deviation
shall not	—used to express what is forbidden by the specification
should *or* may *or* optional	— not mandatory. Used to express either: 1. what is recommended by the specification without forbidding anything (“should”) 2. what is permissible within the limits of the specification (“may” or “optional”)
should not	—used to indicate that something is discouraged but not forbidden by the specification
must	—used to indicate either: 1. an indisputable statement of fact that is always true regardless of the circumstances 2. an implication or natural consequence if a separately-stated requirement is followed
can	—used to express a statement of possibility or capability

Table 1.1: Language conventions terms and definitions

Where more than one item is permitted but not required, the choices to include or support those items are independent from one another unless the specification explicitly states otherwise. Each item that is implemented shall be implemented exactly as written without deviation.

1.1.1.1 Implementation alternatives

When specification content indicates that there are multiple alternatives to satisfy specification requirements, if one alternative is explained or illustrated in an example it is not intended to limit other alternatives that the specification requirements permit.

1.1.1.2 Discrepancies

It is the goal of Bluetooth SIG that specifications are clear, unambiguous, and do not contain discrepancies. However, members can report any perceived discrepancy by filing an erratum and can request a test case waiver as appropriate.

1.1.2 Reserved for Future Use

Where a field in a packet, Protocol Data Unit (PDU), or other data structure is described as "Reserved for Future Use" (irrespective of whether in uppercase or lowercase), the device creating the structure shall set its value to zero unless otherwise specified. Any device receiving or interpreting the structure shall ignore that field; in particular, it shall not reject the structure because of the value of the field.

Where a field, parameter, or other variable object can take a range of values, and some values are described as "Reserved for Future Use," a device sending the object shall not set the object to those values. A device receiving an object with such a value should reject it, and any data structure containing it, as being erroneous; however, this does not apply in a context where the object is described as being ignored or it is specified to ignore unrecognized values.

When a field value is a bit field, unassigned bits can be marked as Reserved for Future Use and shall be set to 0. Implementations that receive a message that contains a Reserved for Future Use bit that is set to 1 shall process the message as if that bit was set to 0, except where specified otherwise.

The acronym RFU is equivalent to Reserved for Future Use.

1.1.3 Prohibited

When a field value is an enumeration, unassigned values can be marked as “Prohibited.” These values shall never be used by an implementation, and any message received that includes a Prohibited value shall be ignored and shall not be processed and shall not be responded to.

Where a field, parameter, or other variable object can take a range of values, and some values are described as “Prohibited,” devices shall not set the object to any of those Prohibited values. A device

receiving an object with such a value should reject it, and any data structure containing it, as being erroneous.

“Prohibited” is never abbreviated.

1.2 Requirements in Tables

Requirements in this specification are defined as "Mandatory" (M), "Optional" (O), "Excluded" (E), “Not Applicable” (N/A), or "Conditional" (C.#). Conditional statements (C.#) are listed directly below the table in which they appear.

- "M” for mandatory. See Table 1.1: Language conventions terms and definitions.
- "O” for optional. See Table 1.1: Language conventions terms and definitions.
- “E” for excluded. “Excluded” means not permitted in this context; cannot be supported or included for this purpose. The item can still be supported or included if allowed for some other purpose (e.g., a feature can be mandatory for one role and excluded for another; a device that supports both roles must support this feature).
- “C.#” for conditional. “Conditional” means that an item is required, optional, or prohibited based on whether one or more other items are supported or included (# represents any number). Within the definition of the condition, if those other items mean that “not permitted” applies, it has the same meaning as “E”.

1.2.1 Table requirements for unused cells

An unused cell is a table cell without a value or content, which is indicated with either the word “none” (without quotation marks) or a hyphen (i.e., a “minus” sign).

1.3 Conformance

Each capability of this specification shall be supported in the specified manner. This specification may provide options for design flexibility, because, for example, some products do not implement every portion of the specification. For each implementation option that is supported, it shall be supported as specified.

2 Configuration

2.1 Roles

The TPMS Profile defines two roles: the TPMS Sensor role and the Monitor role.

2.1.1 Profile role support requirements

Devices that implement the TPMS Profile shall implement at least one profile role as specified in Table 2.1.

Profile role	Requirement	Description
TPMS Sensor	C.1	A device that reports data related to tire pressure, tire temperature, and optionally tire acceleration to one or more Monitors.
Monitor	C.1	A device that receives data from one or more TPMS Sensors.

Table 2.1: Role requirements for devices implementing TPMS Profile

C.1: Mandatory to support at least one role.

2.1.2 Primary and Secondary Monitors

The Monitor role includes two classes of Monitors that have different privileges:

- Primary Monitor. In most cases, this is the monitor associated with the vehicle.
- Secondary Monitor. In most cases, this is a tool used at the TPMS service station.

Both classes of Monitor can receive TPMS Advertising Data and connect to a TPMS Sensor to read characteristic values. However, only a Primary Monitor can read the value of the TPMS Signing Key characteristic (see Section 4.3.5) and write new values to the characteristics of the TPMS Service [1].

For more information, see Section 3.2.6 and Section 3.1.7 of the TPMS Service [1].

2.2 Role and service relationships

In Connected Mode, the TPMS Sensor and Monitor profile roles relate to Generic Attribute Profile (GATT) roles as follows:

- The TPMS Sensor shall be a GATT server.
- The Monitor shall be a GATT client.

Figure 2.1 shows the relationships between services and the Monitor and TPMS Sensor profile roles. The profile roles are represented by yellow boxes. Services (i.e., TPMS Service, Device Information Service, and Battery Service) are represented by orange boxes. Services shown in dashed boxes are optional.

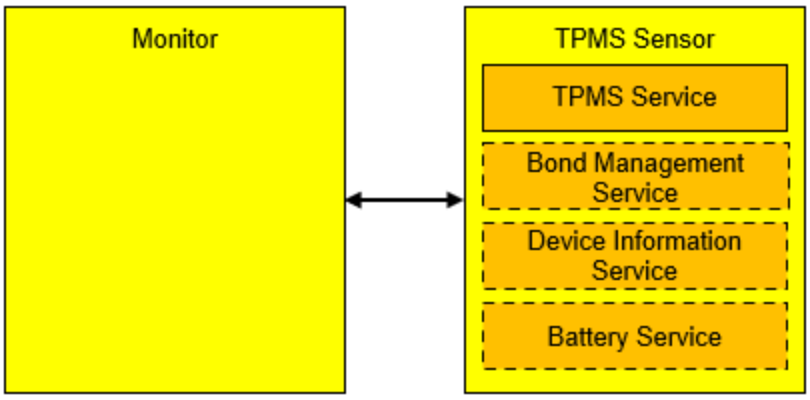

Figure 2.1: TPMS Profile and Service relationships

A TPMS Sensor instantiates the TPMS Service [1] and may instantiate other services such as the Device Information Service [4], Battery Service [6], and Bond Management Service [7].

2.3 Concurrency limitations and restrictions

In Monitoring Mode, a Monitor may receive multiple advertisements that contain advertisements from multiple TPMS Sensors. Although advertisements from separate TPMS Sensors may occasionally collide, the probability of such collisions is low because of the low duty cycle employed. In this context, a low duty cycle means that a brief burst of data transmissions is followed by a prolonged period of inactivity (see Section 3.1.1),

A Monitor may establish concurrent connections with multiple TPMS Sensors.

A TPMS Sensor may establish concurrent connections with multiple Monitors.

2.4 Topology limitations and/or restrictions defined by the Generic Access Profile

This section describes topology limitations and restrictions for the TPMS Profile.

In Connected Mode:

- The TPMS Sensor shall use the Generic Access Profile (GAP) Peripheral role (see Section 5).
- The Monitor shall use the GAP Central role (see Section 5).

In Monitoring Mode:

- The TPMS Sensor shall use the GAP Broadcaster role or the GAP Peripheral role.
- The Monitor shall use the GAP Observer role or the GAP Central role.

Table 2.2 summarizes the requirements for support of different GAP roles for the TPMS Sensor and Monitor.

GAP role dependency	Support in TPMS Sensor	Support in Monitor
GAP Broadcaster role	M	E
GAP Observer role	E	M
GAP Peripheral role	M	E
GAP Central role	E	M

Table 2.2: GAP role dependencies

Table 2.3 describes requirements for support of additional GAP Link Layer features specified in Table 2.2.

GAP feature dependency/ Link Layer feature	Support in TPMS Sensor	Support in Monitor
LE Encryption (see Volume 6, Part B, Section 4.6.1, in [2])	M	M
LL Privacy (see Volume 6, Part B, Section 4.6.7, in [2])	M	M

Table 2.3: Core feature inter-layer dependencies

2.5 Dependencies on other specifications external to the Core

There are no dependencies on other specifications external to the Bluetooth Core Specification [2].

3 TPMS Sensor role requirements

A TPMS Sensor shall instantiate one and only one instance of the TPMS Service [1]. See specific recommendations and requirements in Section 3.3. The TPMS Service shall be instantiated as a «Primary Service».

A TPMS Sensor should instantiate the Device Information Service (DIS) [4].

A TPMS Sensor may instantiate the Bond Management Service (BMS) [7].

A TPMS Sensor should instantiate the Battery Service (BAS) [6].

A summary of the TPMS Sensor service requirements is specified in Table 3.1.

Service/role	Support in TPMS Sensor
TPMS Service	M
Bond Management Service	O
Device Information Service	O
Battery Service	O

Table 3.1: TPMS Sensor service requirements

3.1 TPMS Sensor operational modes

Three modes of operation are defined: Monitoring Mode (see Section 3.1.1), Connectable Mode (see Section 3.1.2), and Connected Mode (see Section 3.1.3). The requirements for support of the three operational modes are defined in Table 3.2.

A TPMS Sensor may be in either operational mode, may switch between modes, and may also support a state in which the TPMS Sensor is not operating in either mode, such as a low-power dormant state.

While this section describes the TPMS Sensor requirements, Section 4 provides the requirements for the Monitors.

Mode	Support in TPMS Sensor
Monitoring Mode	M
Connectable Mode	M
Connected Mode	M

Table 3.2: TPMS Sensor requirements for support of operational modes

3.1.1 Monitoring Mode

In Monitoring Mode, the TPMS Sensor sends periodic updates of tire-pressure data and related sensor data in advertising packets, and the Monitor scans for the advertising packets. Monitoring Mode is connectionless: the TPMS Sensor measurement data is conveyed without requiring that a connection is established.

In Monitoring Mode, the TPMS Sensor shall be in GAP Broadcast mode, as defined in Volume 3, Part C, Section 9.1 in [2]. The TPMS Sensor shall use legacy advertising PDUs on the Bluetooth® Low Energy (LE) 1-megabit physical layer (1M PHY). The format of the advertising PDUs is defined in Section 3.3.

To minimize power consumption, the TPMS Sensor should spend most of the time in the lowest possible power state, periodically entering GAP Broadcast mode (see Volume 3, Part C, Section 9.1 in [2]) to send a burst of advertising packets. The Monitor scans for the advertising packets from the TPMS Sensor for the sensor's measurements updates.

Under normal operating conditions, there is a period of several minutes between updates of the TPMS Sensor readings; short bursts of advertising (Advertising State) may be separated by long periods without advertising (Standby State). Therefore, while in Monitoring Mode, the Server normally alternates between the Advertising State and the Standby State, as shown in Figure 3.1.

The Standby State duration may range between several seconds and several hours, depending on factors such as whether the vehicle is being driven or is stationary.

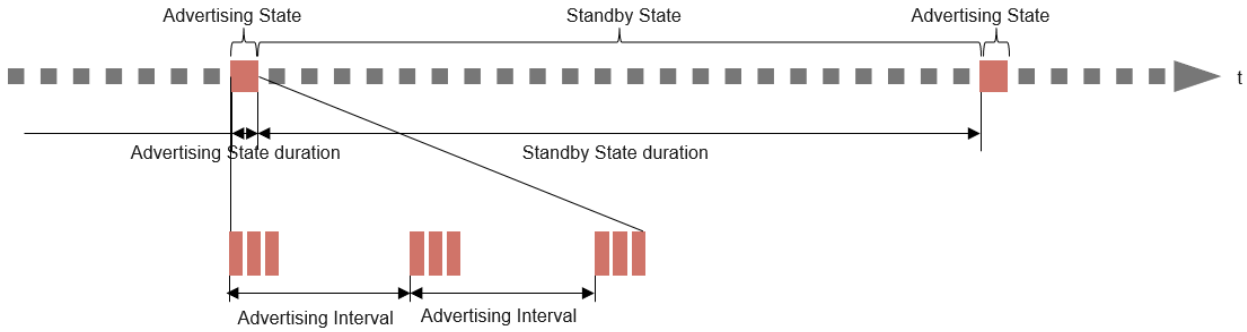

Figure 3.1: Bursts of advertising in Monitoring Mode

When the TPMS Sensor is in the Advertising State, it sends a burst of non-connectable advertising packets to allow Monitors to receive the measured tire state, including pressure and temperature, without establishing a connection.

Since the Monitor does not acknowledge receipt of the advertising packets, the TPMS Sensor should select the advertising interval and the duration of the Advertising State such that at least several advertising packets are transmitted. The recommended value for the advertising interval is 20 milliseconds (ms). The recommended number of Advertising Events is 10, resulting in the Advertising State duration of about 200 ms.

The manufacturer may choose to expose or permit modification of the durations of the Advertising State and Standby State via the TPMS Duty Cycle characteristic (see Section 4.3.3). If the TPMS Duty Cycle

characteristic is exposed, then the TPMS Sensor shall use the durations of the Advertising State and the Standby State as published in the TPMS Duty Cycle characteristic.

If the Advertising State duration and the Standby State duration are configurable through the TPMS Duty Cycle characteristic, the TPMS Sensor should reject setting the TPMS Duty Cycle characteristic such that a lower than recommended number of Advertising Events are sent within one Advertising State.

The values of the Advertising State and Standby State durations exposed via the TPMS Duty Cycle characteristic apply to the behavior of the TPMS Sensor in normal conditions. The TPMS Sensor may adjust the advertising behavior if it detects rapid pressure or temperature change. For example, the driver, upon reentering the vehicle, could immediately receive a warning about a detected abnormal tire condition. This behavior is determined by the implementation.

The TPMS Sensor should leave the Standby State and enter the Advertising State when the vehicle transitions from stationary to moving and from moving to stationary (see Section 3.2.2). Because the Primary Monitor is also aware of when the vehicle's motion status changes, the Primary Monitor can dynamically increase the scanning duty cycle to increase its likelihood of receiving the advertisement from the TPMS Sensors and presenting the data to the user in a timely manner.

If a manufacturer-defined alert condition arises, then the TPMS Sensor should decrease the duration of the Standby State, or transition to Connectable Mode, as described in Section 3.1.2. While an alert condition applies, the TPMS Sensor can disregard any value set by the TPMS Duty Cycle characteristic.

3.1.2 Connectable Mode

To establish a connection with a Monitor, the TPMS Sensor switches to a GAP Limited Discoverable Mode sending connectable undirected advertising events on the LE 1M PHY (see Volume 3, Part C, Section 9.3 in [2]). The recommended advertising interval for the TPMS Sensor in Connectable mode is 1.28 seconds.

The TPMS Sensor can also employ an advertising burst scheme similar to Monitoring Mode (see Section 3.1.1) using connectable undirected advertising events.

3.1.3 Connected Mode

While the TPMS Sensor is in Connected Mode, an asynchronous connection-oriented logical transport is established between the TPMS Sensor and the Monitor. The TPMS Sensor may allow a Monitor to pair and perform GATT characteristic read and write operations.

Note that as stated in Section 2.1.2, only the Primary Monitor is allowed to read the value of the TPMS Signing Key characteristic or to perform any write operation.

In Connected Mode, the receiver can detect errors in received packets and request retransmission until the errors are removed.

If a change in value for the tire pressure or tire temperature occurs during a connection, the TPMS Sensor sends a notification of the characteristic that contains the updated value to the connected Monitor.

After the connection is established, the TPMS Sensor should maintain the connection until the connection is terminated by the Monitor. The TPMS Sensor may disconnect from the Monitor after the manufacturer-defined timeout.

While the TPMS Sensor is in Connected Mode, the TPMS Sensor may also continue to send non-connectable advertising packets (i.e., be in Monitoring Mode), or continue to send connectable advertising packets (i.e., be in Connectable Mode).

3.2 TPMS Sensor state machine

In the context of the TPMS Profile, a TPMS Sensor may be in one of the following states:

- Parked state (see Section 3.2.1)
- Early Driving state (see Section 3.2.2)
- Early Driving Primary Monitor Pairing state (see Section 3.2.3)
- Driving state (see Section 3.2.4)
- Early Parked state (see Section 3.2.5)
- Service state (see Section 3.2.6)

Figure 3.2 shows an example of the TPMS Sensor state machine. The timeouts shown in the figure are illustrative examples and may change based on specific implementation requirements.

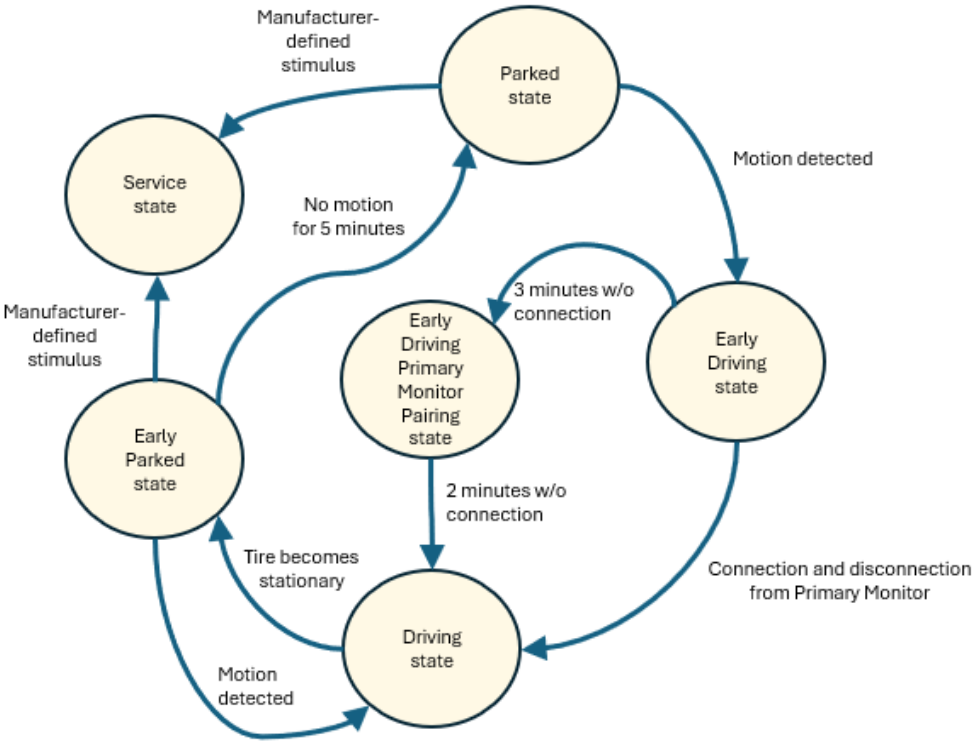

Figure 3.2: TPMS Sensor sample state machine

3.2.1 Parked state

While in the Parked state (i.e., the TPMS Sensor does not detect tire rotation), the TPMS Sensor may be completely off, may be in Connectable Mode (see Section 3.1.2), or may be in Monitoring Mode (see Section 3.1.1).

When the TPMS Sensor detects motion, the TPMS Sensor should switch to the Early Driving state (see Section 3.2.2).

TPMS Sensors that cannot detect motion will not switch to the Early Driving state. In this case, while in the Parked state, the TPMS Sensor shall be in either Connectable Mode or Monitoring Mode.

If the TPMS Sensor detects a manufacturer-defined stimulus such as rapid pressure change, then it should switch to the Service state (see Section 3.2.6).

3.2.2 Early Driving state

Some TPMS Sensors may support bonding while the vehicle is moving to support the case that a TPMS Sensor has been moved from one vehicle to another while the vehicle was parked. To support this case, the TPMS Sensor needs to be connectable in the Early Driving state to allow the Primary Monitor to connect and then confirm to the TPMS Sensor that the TPMS Sensor has not been moved and does not need to create a new bond.

While the TPMS Sensor is in the Early Driving state, the following requirements apply:

- If the TPMS Sensor does not support bonding in the Early Driving state, then the TPMS sensor may be in the non-connectable Monitoring Mode as defined in Section 3.1.1 or in Connectable Mode (see Section 3.1.2).
- If the TPMS Sensor supports bonding in the Early Driving state, then the TPMS sensor shall be in Connectable Mode.
- The format of the TPMS Advertising Data is defined in Section 3.3. The Rotating/Stationary bit of the Indicators field of the TPMS Advertising Data shall be set to 1 (Rotating).
- If the TPMS Sensor is in Connectable Mode, the TPMS Sensor should set up the Filter Accept List to only allow the Primary Monitor to connect.
- The TPMS Sensor shall stay in the Early Driving state for a certain time since entering the state or until the Primary Monitor establishes authenticated connection (for the TPMS sensors that use Connectable Mode). If the TPMS Sensor exposes the TPMS Duty Cycle characteristic, then how long the TPMS Sensor stays in the Early Driving state is published in the Early Driving State Duration field of the TPMS Duty Cycle characteristic.

If the Primary Monitor connects, authenticates, and disconnects, then the TPMS Sensor shall move to the Driving state (see Section 3.2.4).

If the connection is disconnected without successful authentication with the Primary Monitor, then the TPMS Sensor shall stay in the Early Driving state if the timeout since entering the Early Driving state has not expired.

If the timeout expires, then the TPMS Sensor switches to the new state as follows:

- If the TPMS Sensor supports bonding in the Early Driving state, then the TPMS Sensor shall switch to the Early Driving Primary Monitor Pairing state (see Section 3.2.3).
- If the TPMS Sensor does not support bonding in the Early Driving state, then the TPMS Sensor shall switch to the Driving state (see Section 3.2.4).

3.2.3 Early Driving Primary Monitor Pairing state

This section only applies to the TPMS Sensors that support bonding in the Early Driving state. This procedure may be used in cases when the TPMS Sensor needs to establish a connection to a new Primary Monitor. For example, the TPMS Sensor may be a part of a trailer that was hooked to a different vehicle, or a tire with the TPMS Sensor has been moved to a different vehicle.

The TPMS Sensor shall be in Connectable Mode (see Section 3.1.2). The TPMS Sensor shall adjust the Filter Accept List to allow connections from any device and shall become bondable.

The format of the TPMS Advertising Data is defined in Section 3.3. The Rotating/Stationary bit of the Indicators field of the TPMS Advertising Data should be set to 1 (Rotating). The Bondable bit of the Indicators field shall be set to 1. The Authenticated Pairing Only bit of the Indicators field shall be set to 1 if the TPMS Sensor only supports the authenticated pairing procedure.

If the bond with the new Primary Monitor is established, then the TPMS Sensor may discard the bonding information associated with the previous Primary Monitor. The TPMS Sensor must also update the value of the TPMS Signing Key characteristic as defined in Section 3.8.2 of [1].

If authenticated connection to a new or the old Primary Monitor is not established within 2 minutes after switching to the Early Driving Primary Monitor Pairing state, then the TPMS Sensor should switch to the Driving state (see Section 3.2.4).

3.2.4 Driving state

While in the Driving state, the TPMS Sensor is not connectable. The TPMS Sensor shall be in Monitoring Mode as defined in Section 3.1.1.

The format of the TPMS Advertising Data is defined in Section 3.3. The Rotating/Stationary bit of the Indicators field of the TPMS Advertising Data shall be set to 1 (Rotating).

When the TPMS Sensor detects a stationary condition, it shall switch to the Early Parked state (see Section 3.2.5).

3.2.5 Early Parked state

While in the Early Parked state, the TPMS Sensor should be in Monitoring Mode as defined in Section 3.1.1. The TPMS Sensor may also be in Connectable Mode (see Section 3.1.2) to allow a Monitor to establish connection.

The format of the TPMS Advertising Data is defined in Section 3.3. The Rotating/Stationary bit of the Indicators field of the TPMS Advertising Data shall be set to 0 (Stationary).

In the Early Parked state the TPMS Sensor may only allow authenticated pairing. If the TPMS Sensor only supports Just Works pairing (see Volume 3, Part H, Section 2.3, in [2]), then the Bondable and the Authenticated Pairing Only bits of the Indicators field of the TPMS Advertising Data shall be set to 0 and the TPMS Sensor shall not allow Primary Monitor bonding in the Early Parked state. See Section 6.2.1 for additional requirements for TPMS Sensor bonding.

If the TPMS Sensor detects its movement while in the Early Parked state, then it shall switch to the Driving state.

The TPMS Sensor shall stay in the Early Parked state for a certain amount of time after entering. If the TPMS Sensor exposes the TPMS Duty Cycle characteristic, then how long the TPMS Sensor stays in the Early Parked state is published in the Early Parked State Duration field of the TPMS Duty Cycle characteristic. The recommended value is 5 minutes. If movement is not detected within that time, then the TPMS Sensor should switch to the Parked state.

If the TPMS Sensor detects a manufacture-defined stimulus such as rapid pressure change, then it should switch to the Service state (see Section 3.2.6).

3.2.6 Service state

A TPMS Sensor enters the Service state to allow connection establishment with the existing Primary Monitor, a new Primary Monitor, or a Secondary Monitor. For example, the connection may be required in a factory when new TPMS Sensors are installed in a vehicle or in the service shop when connection from a Secondary Monitor is required.

After entering the Service state, the TPMS Sensor shall be in Connectable Mode (see Section 3.1.2). The TPMS Sensor shall stay in Connectable Mode while the stimulus is being applied (e.g., while the pressure is increasing) and for some time after the stimulus is stopped. The duration of how long the TPMS Sensor is waiting for the connection from a Monitor in the Service state may be exposed in the Service State Duration field of the TPMS Duty Cycle characteristic. The recommended value is 1 minute. If a connection is not established within that time after the stimulus has stopped, then the TPMS Sensor should switch from the Service state to the Parked state.

If the TPMS Sensor enters the Service state while any other Monitor (e.g., the Primary Monitor) is still connected, then the TPMS Sensor may disconnect the connected Monitor(s) or enter the Connectable Mode and maintain concurrent connections if the TPMS Sensor can do so.

The format of the TPMS Advertising Data is defined in Section 3.3. If applicable, the Indicators field of the TPMS Advertising Data shall indicate the reason for advertising (e.g., the Pressure Change bit shall be set to 1 if the TPMS Sensor is advertising because of the change of tire pressure).

If the TPMS Sensor is bondable in the Service state, then the Bondable bit of the Indicators field of the TPMS Advertising Data shall be set to 1. The Authenticated Pairing Only bit shall be set to 1 if the TPMS

Sensor only accepts the authenticated pairing procedure (see Section 6.2.1 for additional requirements for TPMS Sensor bonding).

If the TPMS Sensor bonds with a Monitor while in the Service state, the first Monitor with which the TPMS Sensor bonds shall be designated as the Primary Monitor, and any Monitors connected after that shall be designated as Secondary Monitors. The Primary Monitor shall remain designated as the Primary Monitor unless and until the TPMS Sensor's settings are restored to their original defaults where no Primary Monitor is assigned. The Primary Monitor can also be changed if the TPMS Sensor detects that it is moving with a different Monitor (see Section 3.2.3).

The TPMS Sensor should maintain the connection until the connection is terminated by the Monitor. The TPMS Sensor may also implement a manufacturer-specific timer (e.g., 5 minutes) to limit the connection time.

3.3 TPMS Sensor advertising data

The TPMS Sensor shall include the «Service Data» Advertising Data (AD) Type with the TPMS Service universally unique identifier (UUID), defined in [3], in the advertising data.

While advertising, the TPMS Sensor is in GAP Limited Discoverable Mode sending connectable undirected advertising events on the 1M PHY.

The «Service Data» AD Type with TPMS Service UUID enables a Monitor to identify a TPMS Sensor before initiating a connection or to monitor the TPMS Sensor state without establishing a connection. The format of the «Service Data» AD Type is defined in Table 3.3.

Data	Requirement	Format
AD Type Service Data (see Part A, Section 1.11 in [5])	M	uint8
TPMS Service UUID	M	uint16
Pressure	M	uint16
Pressure Accuracy	M	uint8
Temperature	M	uint8
Indicators	M	boolean[8]
Option [i]	C.1	Variable
Sequence Number (SEQ)	M	uint32
Message Authentication Code (MAC)	M	uint32

Table 3.3: TPMS Service advertising data format

C.1: The TPMS Sensor implementation shall select which optional fields to include such that the total length of the TPMS Service advertising data does not exceed 31 octets.

Note that while the TPMS Sensor is advertising in Connectable Mode, the advertising data must also contain the Flags AD Type (see Section 1.3 in [5]).

3.3.1 AD Type Service Data field

The 8-bit AD Type Service Data field shall be included and shall indicate the «Service Data» AD Type.

3.3.2 Tire Pressure Monitoring Service UUID field

The 16-bit Tire Pressure Monitoring Service UUID field shall be included and shall be the UUID for the TPMS Service.

3.3.3 Pressure field

The format of the Pressure field matches the format of the Pressure field of the Tire Pressure characteristic (see Section 3.2.1.1 in [1]). The value shall provide the absolute air pressure in the tire measured by the TPMS Sensor.

3.3.4 Pressure Accuracy field

The format of the Pressure Accuracy field matches the format of the Pressure Accuracy field of the Tire Pressure characteristic (see Section 3.2.1.2 in [1]). The value shall provide the accuracy of the value of the Pressure field as estimated by the TPMS Sensor.

3.3.5 Temperature field

The format of the Temperature field matches the format of the Temperature field of the Tire Temperature characteristic (see Section 3.3.1.1 in [1]). The value shall provide the temperature measured by the TPMS Sensor.

3.3.6 Indicators field

Table 3.4 defines the possible values for the Indicators bits.

Bit	Indicator	Description
0	Rotating/Stationary	If set to 0: TPMS Sensor is stationary or detection is unsupported If set to 1: Rotation detected
1	Pressure Change (Note 1)	If set to 0: Pressure change not detected If set to 1: Significant pressure change detected
2	Battery Low (Note 2)	If set to 0: Battery charge is not low If set to 1: Battery charge is low

Bit	Indicator	Description
3	Bondable	If set to 0: TPMS Sensor is in non-bondable mode If set to 1: TPMS Sensor is in bondable mode
4	Authenticated Pairing Only	If set to 0: Unauthenticated pairing procedure is supported If set to 1, Only authenticated pairing procedure is accepted
5	Rotation Direction (Note 3)	If set to 0: TPMS Sensor is rotating clockwise, rotation is not detected, or rotation direction detection is not supported If set to 1: TPMS Sensor is rotating counterclockwise
6	RFU	RFU
7	Extension	If set to 0: There are no additional octets If set to 1: An additional octet is included (bits 8 to 15)

Table 3.4: Values for the Indicators field bits in advertising data

Note 1: Whether a change in the pressure is considered significant enough to report is determined by the implementation.

Note 2: Whether the battery level is considered low is determined by the implementation.

Note 3: The clockwise and counterclockwise directions are reported from the point of view of a person looking from the outside of the car facing the hubcap or wheel rim.

3.3.6.1 Extension bit additional octet

The Extension bit shall be set to 0 for Version 1.0 of the TPMS Profile specification. If the Extension bit is set to 1, then an additional octet shall be included (bits 8 to 15). The most significant bit of the next octet (bit 15) will be used as the Extension bit in the same way as shown in Table 3.4: if the Extension bit is set to 1, then another octet shall be added, and so on. This method is defined to allow future extension of the Indicators field. A Monitor shall be able to resolve the total length of the Indicators field based on the value of the Extension bits in each of the octets.

3.3.7 Option field

The TPMS Sensor may include zero or more Option fields. Table 3.5 defines the format of the Option field.

Field	Format
Option Length and Type	uint8
Option Data	Variable

Table 3.5: The format of the Option field in advertising data

3.3.7.1 Option Length and Type field

The Option Length and Type field a single-octet field, split into two 4-bit fields: Option Type and Option Length, as defined in Table 3.6.

Bit	Field
0-3	Option Type
4-7	Option Length

Table 3.6: Option Length and Type field format

The Option Length field represents the size of the Option Data field.

Valid values for the Option Type field are defined in Table 3.7.

Option Type code	Option Type description
0x0	RFU
0x1	Temperature Accuracy
0x2	Position
0x3	Angle Data
0x4	Acceleration Data
0x5-0xF	RFU

Table 3.7: Option Type codes

3.3.7.2 Option Data field

The format of the Option Data field depends on the Option Type code. Possible values of the Option Type field and corresponding Option Data field are defined in the following sections.

3.3.7.2.1 Option Type: Temperature Accuracy

Table 3.8 defines the format of the Temperature Accuracy option.

Option Type	Option Type Code	Option Data Format
Temperature Accuracy	0x1	uint8

Table 3.8: Temperature Accuracy option

The format and the value of the Temperature Accuracy option match the format and the value of the Temperature Accuracy field of the Tire Temperature characteristic (see Section 3.3.1.2 in [1]). The value provides the accuracy of the value of the Temperature field as estimated by the TPMS Sensor.

3.3.7.2.2 Option Type: Position

Table 3.9 defines the format of the Position option.

Option Type	Option Type Code	Option Data Format
Position	0x2	uint8

Table 3.9: Position option

The format and the value of the Position option match the format and the value of the TPMS Sensor Position characteristic (see Section 3.7 in [1]). The value indicates the position of the TPMS Sensor in the vehicle.

3.3.7.2.3 Option Type: Angle Data

Table 3.10 and Table 3.11 define format of the Angle Data option.

Option Type	Option Type Code	Option Data Format
Angle Data	0x3	struct

Table 3.10: Angle Data option

Option Data field	Option Data Format
Angle	uint16
Angular Frequency	uint16
Time Offset	uint16

Table 3.11: Option Data field format for Angle Data option

3.3.7.2.3.1 Option Data value: Angle field

The Angle field is 2 octets long and provides the measured angle in degrees of the location on the wheel rim of the TPMS Sensor at the time when the measurement was taken (i.e., the Time Offset before the start of the advertising event (see Section 3.3.7.2.3.3). Table 3.12 defines possible values of the Angle field.

Value	Description
0	The TPMS Sensor is located at the topmost possible position
0x0001-0x0167	The angle of the TPMS Sensor position (1 to 359 degrees)
0x0168-0xFFFF	RFU

Table 3.12: Angle field format

3.3.7.2.3.2 Option Data value: Angular Frequency field

The Angular Frequency field is 2 octets long and provides the measured angular frequency of the wheel in degrees per second at the time when the measurement was taken (i.e., the Time Offset before the start of the advertising event (see Section 3.3.7.2.3.3). Table 3.13 defines possible values of the Angular Frequency field.

Value	Description
0	The TPMS Sensor is stationary
0x0001-0x3FFF	The angular frequency of the TPMS Sensor (1 to 16,383 degrees per second)
0x4000-0xFFFF	RFU

Table 3.13: Angular Frequency field format

3.3.7.2.3.3 Option Data value: Time Offset field

The Time Offset field is 2 octets long and specifies the delta between the time the measurement was taken and the time the TPMS Sensor sends the first advertising packet of the advertising event.

The Time Offset field is increased for every new advertising event sent in the Advertising State.

Table 3.14 defines possible values of the Time Offset field.

Value	Description
0x0000-0xEA60	Time since measurement in 100-microsecond increments (0 to 6 seconds)
0xEA61-0xFFFF	RFU

Table 3.14: Time Offset field format

3.3.7.2.4 Option Type: Acceleration Data

Table 3.15 and Table 3.16 define format of the Acceleration Data option.

Option Type	Option Type Code	Option Data Format
Acceleration Data	0x4	struct

Table 3.15: Acceleration Data option

Option Data field	Option Data Format
Acceleration	uint16
Acceleration Samples Sequence	variable

Table 3.16: Option Data field format for Acceleration Data option

3.3.7.2.4.1 Option Data value: Acceleration field

The format of the Acceleration field matches the format of the Tire Acceleration characteristic (see Section 3.4.1 in [1]). If the size of the Acceleration Samples Sequence field (see Section 3.3.7.2.4.2) is zero, then the value shall provide the instantaneous acceleration of the tire as measured by the TPMS Sensor. If the size of the Acceleration Samples Sequence field is not zero, then the value of the Acceleration field shall represent the median of the acceleration measurements.

3.3.7.2.4.2 Option Data value: Acceleration Samples Sequence field

The Acceleration Samples Sequence field is N octets long and provides a sequence of N acquired Acceleration Samples, relative to the value of the Acceleration field (see Section 3.3.7.2.4.1). The values of the Acceleration Samples Sequence field are included in chronological order, meaning that the first measurement is located at index zero, the second at index one, and so on. Each single Acceleration Sample is 1 octet long. Table 3.17 defines possible values of the Acceleration Sample field.

Value	Description
0x00-0x7E	Positive acceleration measured by the TPMS Sensor relative to the Acceleration Median in 1/16 g, from 0 g to 12714/16 g.
0x7F	Positive acceleration measured by the TPMS Sensor relative to the Acceleration Median is 12715/16 g or higher.
0x82-0xFF	Negative acceleration measured by the TPMS Sensor relative to the Acceleration Median in 1/16 g, from -12714/16 g to -1/16 g.

Value	Description
0x81	Negative acceleration measured by the TPMS Sensor relative to the Acceleration Median is -12715/16 g or lower.
0x80	RFU

Table 3.17: Acceleration Samples Sequence field format

The number of acceleration samples included in the Acceleration Samples Sequence field shall be selected such that the total size of the advertising data field is less than or equal to 31 octets.

3.3.8 SEQ field

The 32-bit SEQ field is used to mitigate replay attacks along with signing of the advertising PDUs (see Section 3.3.9). The TPMS Sensor shall increase the SEQ field each time the data in the advertising data changes or every time the TPMS Sensor enters the Advertising State (new burst of advertising events is started).

The value of SEQ field shall not roll over while the TPMS Sensor uses the same signing key. To avoid the rollover, the TPMS Sensor shall change the value of the signing key (i.e., the value of the TPMS Signing Key characteristic is modified (see Section 3.8 in [1]) and reset the SEQ to 0.

3.3.9 MAC field

The TPMS Sensor may use one of the following methods for signing the TPMS Service advertising data:

- Hash-based Message Authentication Code algorithm (HMAC): The MAC field is an HMAC that combines the SHA-256 hash function with a secret key (see Section 3.3.9.1).
- Cypher-based Message Authentication Code (CMAC): The MAC field is a CMAC (see Section 3.3.9.2).

The TPMS Service specifies which method is used to sign the TPMS Service advertising data in the TPMS Properties characteristic (see Section 3.5 in [1]).

The TPMS Service publishes the key which is used for either HMAC or CMAC calculations in the TPMS Signing Key characteristic (see Section 3.8 in [1]).

The MAC shall be calculated for the portion of the TPMS Service advertising data starting from the TPMS Service UUID field and including the SEQ field.

3.3.9.1 HMAC-SHA-256 function

RFC 2104 [8] defines HMAC as a mechanism for message authentication using cryptographic hash functions. FIPS PUB 180-4 [9] defines the SHA-256 secure hash algorithm. The SHA-256 algorithm is used as a hash function for the HMAC mechanism for the HMAC-SHA-256 function. The TPMS Service

defines HMAC-SHA-256 as a function that takes two inputs and results in one output. The inputs to HMAC-SHA-256 are as follows:

- k is the 128-bit key.
- m is variable-length data to be authenticated.

The HMAC-SHA-256 function generates a MAC defined in [8] as follows:

$$HMAC\text{-}SHA\text{-}256_k(m) = SHA\text{-}256((k0 \oplus opad) \,||\, SHA\text{-}256((k0 \oplus ipad) \,||\, m))$$

Where:

- SHA-256 is the secure hash algorithm defined in [9].
- k0 is the k with the 0x00 octet appended 32 times to the end.
- opad is the 0x5C octet repeated 64 times.
- ipad is the 0x36 octet repeated 64 times.

The resulting MAC value is calculated as:

$$MAC = HMAC\text{-}SHA\text{-}256_k(m) \bmod (2^{32})$$

3.3.9.2 AES-CMAC function

RFC-4493 [10] defines the CMAC that uses AES-128 as the block cipher function, also known as AES-CMAC. The inputs to AES-CMAC are as follows:

- m is the variable length data to be authenticated.
- k is the 128-bit key.

The 128-bit MAC is generated as follows:

$$MAC = AES\text{-}CMAC_k(m) \bmod (2^{32})$$

3.4 Incremental TPMS Service requirements

This section describes additional TPMS Sensor requirements beyond those defined in the TPMS Service [1].

3.4.1 Monitoring Mode duty cycle

The TPMS Sensor may expose the TPMS Duty Cycle characteristic (see Section 4.3.3), which defines various timing parameters of the TPMS Monitor state machine implementation.

Note: Due consideration must be given to achieving a balance between power consumption and the probability of data being delivered successfully, particularly in a poor radio frequency environment.

The duration of the advertising period may be set by the following methods:

- If the TPMS Sensor exposes the writable TPMS Duty Cycle characteristic, the Primary Monitor may update the state machine timing as described in Section 4.3.3.
- If the TPMS Sensor does not expose the writable TPMS Duty Cycle characteristic, the TPMS Sensor is using fixed values for the state machine timing that are specified by the manufacturer.
- The TPMS Sensor may provide an implementation-specific, out-of-band method of adjusting the TPMS Sensor behavior.

If exposed by the TPMS Service, the actual durations shall be accurate to within plus or minus 5 percent of the expected values as determined by any of the methods described in this section.

3.5 Incremental Bond Management Service requirements

If the TPMS Sensor supports the Bond Management Service, then the TPMS Sensor shall only allow the Primary Monitor to access the Bond Management Control Point characteristic.

If a Secondary Monitor attempts to write to the Bond Management Control Point characteristic, then the TPMS Sensor shall reject the Write request and return the Write Request Rejected error code [5].

3.6 Incremental Device Information Service requirements

If the TPMS Sensor supports the Device Information Service, then the Manufacturer Name String characteristic, the Model Number String characteristic, the Serial Number String characteristic, and the Software Revision String characteristic should be supported, as defined in [4].

The TPMS Sensor shall allow a Monitor to access characteristics of the Device Information Service over the unencrypted link.

4 Monitor role requirements

This section describes the Monitor requirements.

The Monitor shall use the TPMS Service [1].

The Monitor may use other services such as the Bond Management Service [7], the Device Information Service [4] and the Battery Service [6].

Table 4.1 lists the requirements for support of the operational modes defined in Section 3.1.

Mode	Support in Monitor
Monitoring Mode	M (see Section 4.4)
Connected Mode	M (see Section 5.1)

Table 4.1: Monitor role requirements for support of operational modes

The TPMS Profile requires using GATT. Table 4.2 lists the requirements for support of the discovery of services and characteristics for the Monitors that support Connected Mode.

Requirement	Support in Monitor	Section
GATT service discovery for TPMS Service	M	4.1
Characteristic discovery for TPMS Service	M	4.2

Table 4.2: Requirements for the Monitor

Table 4.3 summarizes the GATT sub-procedure requirements that are in addition to those required for use by all GATT clients. Requirements in this section represent a minimum set of requirements for a Monitor. Other GATT sub-procedures may be used if they are supported by both the client and server.

GATT sub-procedure	Monitor requirements
Discover All Primary Services	C.1
Discover Primary Service by Service UUID	C.1
Discover All Characteristics of a Service	C.2
Discover Characteristics by UUID	C.2
Discover All Characteristic Descriptors	C.3

GATT sub-procedure	Monitor requirements
Read Characteristic Value	M
Write Characteristic Value	C.3
Write Characteristic Descriptors	C.3

Table 4.3: Additional GATT sub-procedure requirements

C.1: Mandatory to support at least one of the service discovery sub-procedures.

C.2: Mandatory to support at least one of the characteristic discovery sub-procedures.

C.3: Mandatory if the Monitor supports the role of Primary Monitor as described in Section 2.1; otherwise Optional.

4.1 Service discovery

When using LE transport and performing primary service discovery, the Monitor shall use either the GATT Discover All Primary Services sub-procedure or the GATT Discover Primary Service by Service UUID sub-procedure.

The Monitor shall discover the TPMS Service and may discover other services such as the Bond Management Service, the Device Information Service, and the Battery Service.

The procedures in Section 4.2 shall be used to discover characteristics for use with the TPMS Service.

4.2 Characteristic discovery

The Monitor shall accept additional optional characteristics in the service records of services used with the TPMS Profile.

The Monitor shall use either the GATT Discover All Characteristics of a Service sub-procedure or the GATT Discover Characteristics by UUID sub-procedure to discover the characteristics of the TPMS Service.

The Monitor shall use the GATT Discover All Characteristic Descriptors sub-procedure to discover any required characteristic descriptors.

Table 4.4 lists the characteristic discovery requirements for the Monitor.

Service	Characteristic	Discovery Requirements for Monitor
TPMS Service [1]	Tire Pressure characteristic	M
	Tire Temperature characteristic	M
	Tire Acceleration characteristic	M
	TPMS Properties characteristic	M
	TPMS Duty Cycle characteristic	M
	TPMS Sensor Position characteristic	M
	TPMS Signing Key characteristic	M
Bond Management Service [7]	Bond Management Control Point characteristic	O
	Bond Management Feature	O
Device Information Service [4]	Manufacturer Name String characteristic	O
	Model Number String characteristic	O
	Serial Number String characteristic	O
	Software Revision String characteristic	O
Battery Service [6]	Battery Level	O

Table 4.4: Characteristic discovery requirements for the Monitor

4.3 Requirements for characteristics

The TPMS Service characteristics that may be exposed by the TPMS Sensor are listed in Table 4.4.

The characteristics that are readable and/or writable, and the meaning and format of each characteristic value, are identified in the TPMS Service [1].

A Primary Monitor may write a new value to any writable characteristic that is exposed by the TPMS Sensor. The characteristics that may have the Write property are identified in the TPMS Service [1].

A Secondary Monitor shall not write to any of the characteristics that are exposed by the TPMS Service (see Section 2.1.2).

4.3.1 Tire Pressure, Tire Temperature, and Tire Acceleration characteristics

Upon initial connection, the Monitor shall configure the Tire Pressure and the Tire Temperature characteristics for notifications by writing to the Client Characteristic Configuration descriptor. The Monitor shall be able to receive notifications of the Tire Pressure and Tire Temperature characteristics.

The Monitor may read the value of the Tire Pressure characteristic to determine the tire pressure and may read the value of the Tire Temperature characteristic to determine the tire temperature.

If the Tire Acceleration characteristic is exposed by the TPMS Sensor, the Monitor may read the value of the Tire Acceleration characteristic to determine the tire acceleration. If the Tire Acceleration is exposed, to determine if the reported tire acceleration value corresponds to radial or tangential acceleration the Monitor shall read the TPMS Properties characteristic.

When a notification of the Tire Pressure characteristic or the Tire Temperature characteristic is received, it signifies to the Monitor that the TPMS Sensor has detected a change in the Tire Pressure value or the Tire Temperature value, respectively. The notification contains the new value.

If the Monitor needs to read two of, or all three of, the Tire Pressure, Tire Temperature, and Tire Acceleration characteristics, the Monitor should use the Read Multiple Characteristic Values sub-procedure to receive all values in one message (see Volume 3, Part G, Section 4.8.4, in [2]).

4.3.2 TPMS Properties characteristic

The Monitor shall read the TPMS Properties characteristic to determine the properties of the TPMS Sensor, including if:

- The TPMS Sensor is reporting radial or tangential acceleration (Tire Acceleration Type field).
- The TPMS Sensor uses the HMAC-SHA-256 or AES-CMAC function to sign the advertising data (MAC Type field).

4.3.3 TPMS Duty Cycle characteristic

The Monitor may read the value of the TPMS Duty Cycle characteristic exposed by a TPMS Sensor to determine the Advertising State duration, Parked Standby state duration, Driving Standby state duration, Early Driving state duration, Early Driving Primary Monitor Pairing state duration, and Service state duration. See Section 3.2 for descriptions of the TPMS Sensor states.

By writing to the TPMS Duty Cycle characteristic, the Primary Monitor may change the timing values specified in TPMS Duty Cycle characteristic.

If the TPMS Sensor responds to a write request with an error code such as Out of Range or Write Request Rejected [5], then the Primary Monitor shall consider the timing values specified in TPMS Duty Cycle characteristic to be unchanged.

4.3.4 TPMS Sensor Position characteristic

The Monitor may read the value of the TPMS Sensor Position characteristic exposed by a TPMS Sensor to determine the location of the tire to which the TPMS Sensor is fitted.

By writing to the TPMS Sensor Position characteristic, the Primary Monitor may perform initial configuration of the TPMS Sensor position and can update the TPMS Sensor position if the physical location of the TPMS Sensor changes (e.g., if the TPMS Sensor with the tire is moved to a different axle during servicing).

If the TPMS Sensor responds to a write request with the Write Request Rejected error code [5], then the Monitor shall consider that the tire position value it requested is not recognized as a valid position by the TPMS Sensor.

The Monitor should cache the tire position associated with the TPMS Sensor so that the Monitor detects the tire position when it receives data from the TPMS Sensor in Monitoring Mode.

4.3.5 TPMS Signing Key characteristic

The Primary Monitor may read the value of the TPMS Signing Key characteristic exposed by a TPMS Sensor to determine the key required to verify the signature of the advertising data.

Upon initial connection, the Monitor shall configure the TPMS Signing Key characteristic for indications by writing to the Client Characteristic Configuration descriptor. Registering to receive indications will allow the TPMS Sensor to indicate to the Monitor when the value of the TPMS Signing Key characteristic has been changed.

4.3.6 General error handling

The Monitor shall be tolerant and behave appropriately if it receives an Attribute Protocol error code. In particular, the Monitor may receive the Write Request Rejected error code [5] upon writing to the TPMS Duty Cycle characteristic or the TPMS Sensor Position characteristic, or upon reading the TPMS Signing Key characteristic. If the Monitor that the received Write Request Rejected error code, should serve as a Primary Monitor for the TPMS Sensor, then the Monitor shall notify the vehicle so that the corrected action is taken.

4.4 Monitoring TPMS Service Data

This section specifies requirements for the Monitor when TPMS Sensors are in Monitoring Mode.

4.4.1 Monitoring setup

During initial connection, the Primary Monitor reads and caches the value of the TPMS Properties characteristic (see Section 4.3.2).

- If TPMS Service advertising data includes the Acceleration field, the Monitor shall use the Tire Acceleration Type bit of the TPMS Properties characteristic to interpret the value of the Acceleration value. If the Tire Acceleration Type bit is set to 1, then the value reported in the Acceleration field

shall be interpreted as radial acceleration. Otherwise, the value reported in the Acceleration field shall be interpreted as tangential acceleration.

- If the MAC Type bit of the TPMS Properties characteristic is set to 1, then the Monitor shall use the HMAC-SHA-256 function to validate the TPMS Service advertising data. Otherwise, the Monitor shall use the AES-CMAC function to validate the TPMS Service advertising data.

The Primary Monitor shall read and cache the value of the TPMS Signing Key characteristic (see Section 4.3.5), which allows the Monitor to verify the validity of the advertising packets. The Monitor shall update the cached value if it receives a TPMS Signing Key characteristic indication.

4.4.2 Monitoring state

While a TPMS Sensor is in Monitoring Mode, the TPMS Service Advertising Data, described in Section 3.3 provides the Monitor with continual connectionless updates of tire pressure measurements and related real-time data.

To receive advertising events from TPMS Sensors, the Monitor should use the Observation procedure using passive scanning as defined in Volume 3, Part C, Section 9.1.2 in [2]. The recommended scan interval is 30 to 60 ms; a scan window is 30 ms.

There can be dozens or even hundreds of TPMS Sensors in the radio frequency range of the Monitor. Unless in a special condition (e.g., when the TPMS Sensor is put in the Service State (see Section 3.2.6), or in the special case when the Primary Monitor fails to detect advertisements from bonded TPMS Sensors (see Section 4.4.3), the Primary Monitor should use the Filter Accept List to filter out unwanted advertising packets.

Because there are generally multiple wheels fitted to a vehicle, the Monitor shall be able to receive and validate TPMS Service Advertising Data from multiple TPMS Sensors. The non-connectable or connectable advertisements from different TPMS Sensors are not coordinated in time, but because of the extremely low duty cycle that is required for TPMS applications, transmissions will be interleaved and received at different moments. Because the advertising data mechanism used in Monitoring Mode is unacknowledged, and therefore the receipt of advertisements cannot be verified, the Monitor shall be tolerant to missing some updates in Monitoring Mode. For example, if the Monitor receives advertising data with Indicators stating that the TPMS Sensor is stationary in two consecutive batches, the Monitor shall not assume that the TPMS Sensor was stationary all the time because the advertisements indicating that the TPMS Sensor was rotating could have been lost.

When receiving connectable or non-connectable advertising from a TPMS Sensor, to validate received TPMS data the Primary Monitor shall verify that the signature of the TPMS Advertising Data is correct. The Monitor shall also verify that the SEQ field of the TPMS Advertising Data is not lower than the previously received value. If verification fails, then the Primary Monitor shall ignore the received advertising packet.

The Monitor shall be able to process Option fields with known Option Types and ignore unrecognized Option Types (see Section 3.3.7).

If the Monitor receives connectable advertising from the bonded TPMS Sensor, then the Monitor shall establish connection to the TPMS Sensor and encrypt the link, essentially performing mutual authentication. The Monitor shall disconnect as soon as it stops using the connection (e.g., if the user stops watching the tire pressure screen, or the TPMS Electronic Control Unit (ECU) completes calculation of the tire location). Disconnection would allow the TPMS Sensor to switch to the low-power Parked state (see Section 3.2.1) or Driving state (see Section 3.2.4).

4.4.3 Bonding while driving

A Monitor that is associated with the TPMS ECU of the vehicle may support pairing with a TPMS Sensor while the vehicle is moving. This procedure may be used to support the case, when a TPMS Sensor has been replaced or has been moved from one vehicle to another, without performing bonding with the new Monitor.

The Monitor is normally configured for a certain number of TPMS Sensors (e.g., four for a passenger vehicle). When the vehicle starts driving after it has been parked long enough so that the tire could be replaced (actual value is determined by the implementation), the Monitor should verify that the TPMS Sensors that were with the vehicle before parking are still present.

If the Monitor fails to detect non-connectable or connectable advertising packets from all previously used TPMS Sensors after application-defined time since the vehicle started moving, then the Primary Monitor should assume that the TPMS Sensor has been replaced or is not functioning properly.

- If the Monitor supports bonding while driving, then the Monitor shall update the Filter Accept List to accept advertisements from any device and shall start searching for the advertising packets from the TPMS Sensor (see Section 3.3), which has the Bondable flag of the Indicators field set to 1. The Monitor may use an application-specific method to identify the TPMS Sensor(s) that belongs to it. For example, the Monitor may use RSSI of the advertising packets, or the fact that several advertising packets from the specific TPMS Sensor are received within a few seconds of moving. If the Monitor detects its new TPMS Sensor, then the Monitor shall establish connection and bond with the TPMS Sensor. Before initiating the bonding procedure, the Monitor may use the Authenticated Pairing Only bit of the Indicators field to find out if authenticated pairing is required by the TPMS Sensor.
- If the Monitor does not support bonding in the driving state, and if the Monitor failed to receive TPMS Sensor data for manufacturer-specific time, then the Monitor should report the fault condition.

4.4.4 Service state

When a user puts the TPMS Sensor in the Service state (see Section 3.2.6), the user may also instruct the Monitor to establish the connection.

The Primary Monitor may use the Service state to establish a bonded relationship with the TPMS Sensor.

The Secondary Monitor may be able to establish a connection and read TPMS Sensor measurements and settings. The Secondary Monitor must not bond with the TPMS Sensor. To establish a secure connection, the Secondary Monitor must set the Bonding Flags field to “No Bonding” in the Pairing Request (see Section 6.2.2).

To modify the TPMS Sensor configuration during the manufacturing process (e.g., when the tire is first assembled), the manufacturing tool must become the Primary Monitor. After the procedure is completed, the manufacturing tool should unbond from the TPMS Sensor (see [7]) before the connection is disconnected to allow bonding by the Primary Monitor associated with the vehicle's TPMS ECU.

5 Connection establishment procedures

This section describes the connection establishment procedures and connection termination procedures between a TPMS Sensor and a Monitor.

5.1 TPMS Sensor connection establishment

The TPMS Sensor may enter Connectable Mode (see Section 3.1.2) in various states as defined in Section 3.2.

5.2 Monitor connection establishment

The Monitor should establish connection when it receives connectable advertisements from a bonded TPMS Sensor.

To establish connection to a TPMS Sensor, the Monitor performs a high duty scan, which allows the TPMS Sensor to use low duty advertising.

5.3 Link loss reconnection procedure

5.3.1 TPMS Sensor in link loss reconnection procedure

When a connection is terminated because of a link loss, the TPMS Sensor should attempt to reconnect to the Monitor by entering Connectable Mode as defined in Section 3.1.2. However, the duration of a reconnection attempt should be limited to no longer than 60 seconds to help preserve the battery life of the TPMS Sensor.

5.3.2 Primary or Secondary Monitor in link loss reconnection procedure

When a connection is terminated because of a link loss, the Monitor should attempt to reconnect to the TPMS Sensor using any of the GAP connection establishment procedures.

Intervention by a user may be required if the TPMS Sensor has ceased sending connectable advertising. For example, if the connection was established while the user was pumping air to the tire, and the link loss occurred, the user may need to start pumping air again for the TPMS Sensor to become connectable.

6 Security requirements

This section describes the security considerations for a TPMS Sensor and Monitor. The Security Modes and Security Levels referred to in this section are defined in GAP [2].

6.1 Connection security

A connection that satisfies LE security mode 1 level 4 should be used for access to all services used by the TPMS Profile, except for service and characteristic discovery (as defined in Volume 3, Part G, Section 8.1, in [2]).

If the authenticated link security option is not possible, then LE security mode 1 level 2 or stronger, with LE Secure Connections pairing (see Volume 3, Part H, Section 2.3.5.6, in [2]) and 128-bit or longer keys (see Volume 3, Part H, Section 2.3.4, in [2]), shall be required for access to all services used by the TPMS Profile, except for service and characteristic discovery, as allowed by the Bluetooth Core specification (see Volume 3, Part G, Section 8.1, in [2]).

Legacy pairing methods and key sizes less than 128 bits shall be rejected.

6.2 Bonding

6.2.1 Pairing with the Primary Monitor

The Primary Monitor shall bond with a TPMS Sensor. To pair with the TPMS Sensor, the Primary Monitor shall set the Bonding Flags field to “Bonding” in the Pairing Request message as defined in Volume 3, Part H, Section 3.5.1, in [2]. The bonding information shall be exchanged and stored.

If the TPMS Sensor indicates the Authenticated Pairing Only bit in the Indicators field of TPMS Sensor advertising data (see Section 3.3.6), and if the Monitor sets the Bonding Flags field to “Bonding” in the Pairing Request message, then the TPMS Sensor shall reject the Pairing Request if IO capabilities of the peer device indicate that the unauthenticated pairing procedure will be used (Volume 3, Part H, Section 2.3.5, in [2]).

The TPMS Sensor may support multiple Primary Monitors if authenticated pairing is performed with every Primary Monitor. If the TPMS Sensor performed authenticated pairing with one Primary Monitor, then the TPMS Sensor shall reject the new Pairing Request if IO capabilities indicate that the unauthenticated pairing procedure will be used.

If the TPMS Sensor performed unauthenticated pairing with one Primary Monitor, then new pairing shall replace the previous Primary Monitor (i.e., keys associated with the old Primary Monitor shall be discarded after the successful pairing with the new Primary Monitor).

6.2.2 Pairing with the Secondary Monitor

The Secondary Monitor shall not bond with a TPMS Sensor. To pair with the TPMS Sensor, the Secondary Monitor shall set the Bonding Flags field to “No Bonding” in the Pairing Request message as defined in Volume 3, Part H, Section 3.5.2, in [2]. The bonding information shall not be exchanged or stored.

The TPMS Sensor may discard pairing data from the Secondary Monitor after the connection has been disconnected.

6.3 Privacy

The privacy feature (Volume 3, Part C, Section 10.7, in [2]) may be supported and enabled. If Resolvable Private Addresses are used, then the TPMS Sensor and a Monitor shall exchange their Identity Resolving Key during the key distribution phase (Volume 3, Part H, Section 3.6.1, in [2]) of the pairing procedure.

7 Acronyms and abbreviations

Acronym/abbreviation	Meaning
1M PHY	1-megabit physical layer
AD Type	Advertising Data Type
CMAC	cypher-based Message Authentication Code
ECU	Electronic Control Unit
GAP	Generic Access Profile
GATT	Generic Attribute Profile
HMAC	hash-based Message Authentication Code algorithm
LE	Low Energy
MAC	Message Authentication Code
SEQ	Sequence Number
TPMS	Tire Pressure Monitoring System
UUID	universally unique identifier

Table 7.1: Acronyms and abbreviations

8 References

[1] Tire Pressure Monitoring Service, Version 1.0 or later

[2] Bluetooth Core Specification, Version 6.1 or later

[3] Bluetooth Assigned Numbers, https://www.bluetooth.com/specifications/assigned-numbers

[4] Device Information Service, Version 1.2 or later

[5] Core Specification Supplement, Version 15 or later

[6] Battery Service, Version 1.1 or later

[7] Bond Management Service, Version 1.0.1 or later

[8] Internet Engineering Task Force, “RFC 2104: HMAC: Keyed-Hashing for Message Authentication”, February 1997, https://tools.ietf.org/html/rfc2104

[9] National Institute of Standards and Technology, “FIPS PUB 180-4: Secure Hash Standard (SHS)”, August 2015, https://www.nist.gov/publications/secure-hash-standard

[10] Internet Engineering Task Force, “RFC 4493: The AES-CMAC Algorithm”, June 2006, https://tools.ietf.org/html/rfc4493