SECUR

Safety Enhancement through Connected Users on the Road

# Deliverable 2.1

## Technical document: Bluetooth Low Energy 5.0

| | | |
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IMT Atlantique

# EXECUTIVE SUMMARY

This document is the technical document of Bluetooth 5.0 technology. It gathers general information, performances KPI (data rate, range & reliability, latency, congestion, mobility and positioning) and technology's characteristics.

BLE is limited for mobility purpose because, today, all the V2X standards and profiles are not applicable to BLE communication. It would not be efficient to use the current standards on the technology and thus, everything needs to be built for the BLE. It might show potential in the distant future. BLE is well suited for direct short-range (typically 100m) opportunistic communications with limited throughput (up to 250/500kb/s).

# ABBREVIATIONS

| | |
|---|---|
| 3GPP | 3rd Generation Partnership Project |
| 4G | 4G is the fourth generation of broadband cellular network technology, succeeding 3G and preceding 5G |
| 5G | In telecommunications, 5G is the fifth-generation technology standard for broadband cellular networks |
| 5GAA | 5G Automotive Association |
| ASIL | Automotive Safety Integrity Level |
| BC | Bicyclist |
| BLE | Bluetooth Low Energy |
| C2C-CC | Car 2 Car Communication Consortium |
| CAM | Cooperative Awareness Message |
| CBR | Channel Busy Ratio |
| C-ITS | Cooperative Intelligent Transport Systems |
| CPM | Cooperative Perception Message<br>These messages broadcast information on detected object to its surrounding. |
| D2VO | Datex-II Vehicle Obstruction |
| D2WRRC | Datex-II Weather Related Road Conditions |
| DENM | Decentralized Environmental Notification Message |
| ECTL | European Certificate Trust List |
| ETSI | European Telecommunications Standards Institute |
| EU | European Union |
| GDPR | General Data Protection Regulation |
| IP | Internet Protocol |
| ITS-G5 | Direct communication technology based on Wi-Fi.<br>European name for WAVE or DSRC. |
| IVS | In-Vehicle Signage |
| KPH | Kilometers per hour |
| KPI | Key Performance Indicator |
| LOS | Line-of-sight |
| LTE | Long Term Evolution |
| MAPEM | MAP Extended Message |
| NLOS | Non-line-of-sight |
| OBU | On-Board Unit |
| PC | Passenger Car |
| PC5 | Direct communication technology based on mobile network (3GPP). PC5 is one part of C-V2X/LTE-V2X that enable direct communication between objects. |
| PD | Pedestrian |
| PDR | Packet Delivery Ratio |
| PER | Packet Error Rate |
| PKI | Public Key Infrastructure |
| PTW | Powered Two-wheeler |
| REL | Release |
| RSU | Road Side Unit |
| RTK | Reel Time Kinematic |
| SB | Steering Board |
| SPATEM | Signal Phase And Timing Extended Message |

| | |
|---|---|
| TTC | Time To Collision |
| UC | Use case |
| UK | United Kingdom |
| Uu | Radio interface in cellular communication between a user equipment (UE) and the cellular network base station. |
| V2I | Vehicle-To-Infrastructure |
| V2N | Vehicle-To-Network (Uu communication) |
| V2P | Vehicle-To-Pedestrian |
| V2V | Vehicle-To-Vehicle |
| V2VRU | Vehicle-To-Vulnerable Road User |
| V2X | Vehicle-To-Everything (i.e. vehicle to any type of other station) |
| VAM | VRU Awareness Message |
| VRU | Vulnerable Road User (motorcyclist, bicyclist and pedestrian) |
| WG | Working Group |
| WP | Work Package |
| WP1 | SECUR Work Package n°1: Accidentology study |
| WP2 | SECUR Work Package n°2: V2X technologies study |
| WP3 | SECUR Work Package n°3: Potential of V2X to improve ADAS performances and final use cases selection |
| WP4 | SECUR Work Package n°4: Development of testing connected targets |
| WP5 | SECUR Work Package n°5: Test and assessment procedures |

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# 1. General information

## 1.1 Technology's name

Bluetooth Low Energy 5.0

## 1.2 Operating frequency band

2,4GHz (2400 MHz – 2483.5 MHz)

## 1.3 Standard (access layer)

### 1.3.1 Standardization organization

Bluetooth SIG (Bluetooth Special Interest Group)

### 1.3.2 Standard level of maturity [draft/in work/released/rework]

Released

### 1.3.3 Is the organization active?

Yes, there are revisions every year in average during the last three years and other BLE specification releases are every three to six months.

## 1.4 Communication profile

Version 5.0

Bluetooth Low Energy is a subset of the Bluetooth specification. The current version is BLE 5.3, but this document will consider BLE 5.0 since no significant improvement was introduced regarding SECUR use cases since version 5.0.

Version 5.0 dates from December 2016. Recent versions include features that can be useful but not mandatory for safety applications. For instance:

- Direction finding (revision 5.1), that is, Angle of Arrival and Angle of Departure
- Arbitrary channel indexing (5.1), that enables the advertiser to select the channels to advertise and the order. For instance, advertiser can use a random channel sequence to reduce chances for collision.
- Classification of Secondary Advertising channels as bad (5.1). In 5.1 the classification is done centrally. In 5.3 the peripheral devices can also participate.
- LE Power Control (5.1). Transmitters can adjust the transmit power. Receivers can request the transmitter to adjust the transmit power.
- Enhanced Attribute Protocol (5.2). An upgrade of the Attribute Protocol that enables concurrent transactions between BLE applications and the BLE host.
- Isochronous channels (5.2). For time sensitive transmissions (e.g. High-quality audio), as well as for synchronized transmissions at multiple receivers.
- Redundant packets (5.3). Allows the receiver's controller to identify and discard redundant packets.

This document focusses on the Advertisement mode of Bluetooth Low Energy (BLE)

Versions 5.1, 5.2 and 5.3 respectively date from January 2019, December 2019 and January 2021.

## 1.5 ALL SUPPORTED COMMUNICATION TYPES (BROADCAST…)

The BLE 5.0 could support two different types of communication, with a connection and without connection. The last one, connectionless (or advertisement) is a new communication mode introduced in BLE 4.0 and improved in this version. The current version allows longer range and larger messages that make BLE beacon more useful in a variety of application. Connection-oriented and connectionless communications could coexist.

In connectionless communication, the information is distributed by broadcast on the advertisement payload to all nodes within range.

The connection-based BLE communication (with a connection) is similar to the classical Bluetooth master-slave (central – peripheral) mode. This mode supports the classical network topology, a piconet. Each device has the capability to operate simultaneously in both roles in different piconets and with multiple devices. This mode obviously requires time to set-up the network and a relatively stable topology along the time, which makes it a poorly appropriate candidate for road safety applications.

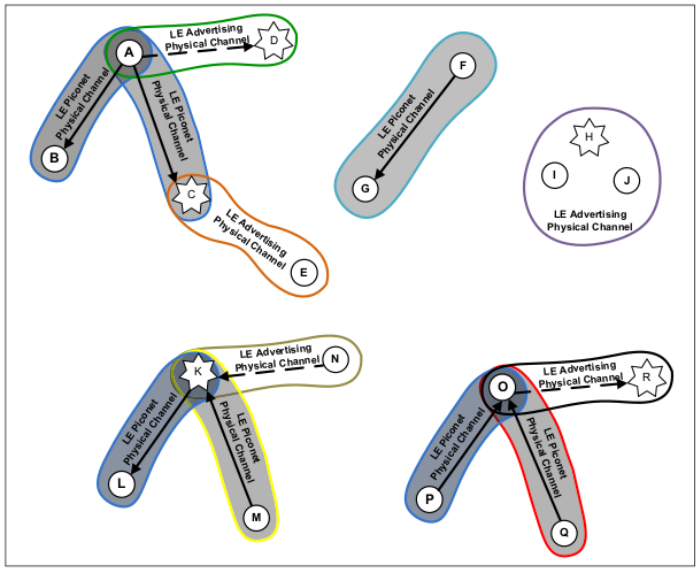


*Figure 1: BLE topology [1]*

### 1.5.1 DIRECT COMMUNICATIONS WITH BLE (ADVERTISEMENTS)

BLE is a short-range communication system that supports connection-oriented and connection-less communications. Due to the real time and sporadicity requirements of the use cases targeted by SECUR, this document focuses on the connection-less mode which can be used to set up direct communications. The connection less mode of BLE is supported by broadcast messages called "Advertisements".

Like Bluetooth Classic, BLE operates in the 2.4 GHz ISM band but uses a different PHY layer (so called LE PHY). BLE combines two multiple access schemes: frequency division multiplexing (FDMA) and time division multiplexing (TDMA). The FDMA uses 40 channels separated by 2 MHz, with channels 37, 38 and 39 dedicated to advertisements. Channels 37, 38, and 39, called *primary advertisement channels*, operate in frequencies that minimize the interference with Wi-Fi. A TDMA based polling scheme allows devices (in connection-based communication) to transmit packets at a predetermined time.

Advertisements are at the core of BLE. Advertisements enable network and service discovery; they also allow the periodic transmission of data. For example, Beacons (e.g., Apple's iBeacon and Google's Eddystone) use advertisements to periodically broadcast data.

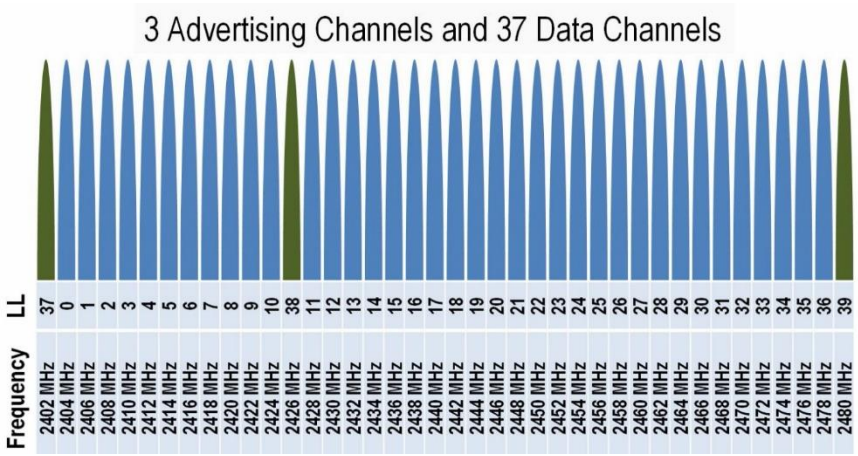


*Figure 2: Channel organisation in BLE (3 advertising and 37 data channels between 2.4 and 2.480 GHz)*

Devices transmit advertisements during transmission events, where frames are broadcast on the primary advertisement channels (Figure 3).
*advInterval* is a configurable value between 20 ms and 3h. *advDelay* is a pseudo-random value in the range [0 ms, 10 ms]. This randomness of *advDelay* reduces the chances for collisions between subsequent transmissions. Note that BLE advertising does not implement any recovery procedure.

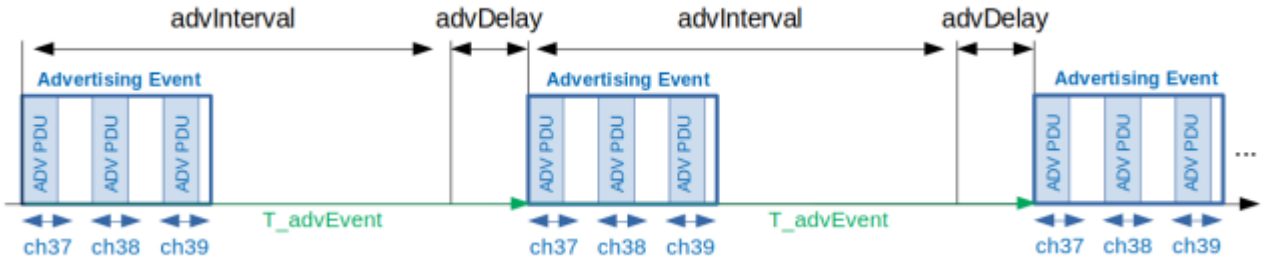


*Figure 3: Scheduling of BLE Advertisement transmission*

In Bluetooth 5.x there are two classes of advertisements: *legacy* and *extended*.

*Legacy advertisements* (sent on the so-called *primary advertising channel*) use a single frame that is broadcast on the primary advertising channels. Legacy advertising frames have a maximum length of 47 bytes, for a maximum advertisement data length of 31 bytes. Legacy advertisement can only be sent using LE 1M PHY (see §1.5.2).

*Extended advertisements* (sent on the so-called *secondary advertising channel*) increase the payload limit to 254 bytes and use two frames. The advertiser transmits a first frame on the primary advertisement channels. This first advertisement points to a second frame transmitted in one of the other 37 channels. This second frame is called AUX_ADV_IND and can use any of the three BLE PHY (LE 1M, LE Coded or LE 2M, see §1.5.2).

Additionally, there are different types of advertisements: directed or not, connectable or not, scannable or not. The legacy "non-connected non-scannable" advertisements is named "ADV NONCONN IND". It is well suited to broadcast sporadic periodic information in a way that is similar to basic ITS messages like for instance, CAM or DENM. Even if the payload has to be

adapted to small advertisement. Other BLE modes are designed to expose devices capabilities and provide access to device resources and do not seem to fit the needs of targeted SECUR uses cases because they require to associate devices prior to establish any communication. At least they would require more adaptations of the ITS services.

### 1.5.2 BLE PHY MODES

While "*advertiser devices*" broadcast advertisement frames the "*scanners*" periodically monitor the advertising channels.

BLE defines two parameters: *scanWindow* is the time spent listening to a given channel; and *scanInterval* is the duration between the start of two consecutive scan windows. For energy efficiency considerations, devices can return to sleep mode between scanning windows. Note that when *scanInterval=scanWindow*, the device scans continuously, except while it is transmitting.

Advertisements use a Gaussian Frequency Shift Keying (GFSK) modulation. The Bluetooth Core Specifcation [1] defines the following coding schemes:

- **LE 1M PHY** (1 Msym/s): 1 bit/symbol => 1 Mb/s
- **LE Coded PHY** (with Forward Error Correction)
  - **S=2**: 2 symbols/bit => 500 kb/s
  - **S=8**: 8 symbols/bit => 125 kb/s
- **LE 2M PHY** (optional) at 2 Msym/s (uncoded only) => 2Mb/s

For instance with LE 1M, a 47-byte long advertisement messages take 376 µs for wireless transmission.

*Table 1 - BLE 5.0 Physical layer comparison [32]*

| | **Physical layer configuration** | | | |
|---|---|---|---|---|
| | ***LE 1M*** | ***LE Coded S=2*** | ***LE Coded S=8*** | ***LE 2M*** |
| **Symbol rate** | 1Ms/s | 1Ms/s | 1Ms/s | 2Ms/s |
| **Data Rate** | 1Mb/s | 500kb/s | 125kb/s | 2Mb/s |
| **Range Multiplier** | 1 | 2 | 4 | 0.8 |
| **Error Control** | CRC | CRC & FEC | CRC &FEC | CRC |
| **PDU Length** | 0-257 bytes | | | |
| **Frequency** | 2400-2483.5 MHz | | | |

## 1.6 V2X SYSTEMS CAPABILITY (V2V, V2I, V2N, V2VRU)

*Table 1 - BLE 5.0 capability by V2X communication types*

| V2X Type | Supported or not? | Mandatory infrastructure(s)/Hardware for the technology operability |
|---|---|---|
| V2V | Supported (but limited) | It will depend on the use cases. It can be used at low speed and low range.<br>BLE 5.0 chipset |
| V2I | Supported | BLE 5.0 chipset |
| V2N | Supported (but limited) | Indirectly possible through V2I2N, but very limited in throughput. And obviously requires the cooperation of a RSU to act as a relay. |
| V2VRU | Supported | BLE 5.0 chipset |

## 1.7 TECHNOLOGY'S DEPLOYMENT MATURITY

This technology is well known, tested and has a high market penetration. It is commonly used in all types of devices and vehicles. The current implementation in automotive industry is dedicated to in-vehicle use-cases. Nevertheless, while not intended for such applications Bluetooth communications are observable from outside vehicles [Klin14]. If Bluetooth available in almost all the market, BLE is not currently deployed in vehicles,

## 1.8 WHERE IS THE TECHNOLOGY USED? (ONLY WITH THE SAME COMMUNICATION PROFILE)

This technology has a very high level of penetration of the automotive market.

Due to its low cost and versatility, BLE became a very popular technology. It is natively integrated into a wide range of microcontrollers, microprocessor, Wi-Fi chips or dedicated modules.
As a result, BLE is available in most smartphones, tablets and computers produced today and thus enables for a quick deployment of new services toward mass customers market without requiring additional equipment investment.
The integration into Wi-Fi chipset makes it easily accessible for automotive manufacturers who already use such kind of devices. A specific integration in vehicles should be performed to insure good communication performances with equipment outside the vehicle. Communication range outside of the vehicle should be validated by measurements and field trials.

# 2. Performances

## 2.1 DATA RATE

### 2.1.1 BANDWIDTH

The bandwidth 2,4GHz (from 2.402GHz to 2.48GHz) is divided in 40 channels, 3 primary (green below) and 37 secondary (blue below). A primary channel is dedicated to advertising and a secondary channel could be used both for advertising and data exchange.

### 2.1.2 PERFORMANCES

BLE 5.0 brings two new PHYs modes (LE 2M / LE Coded).
This gives us 3 different PHYs modes: LE 1M, LE 2M, LE Coded.

The applications can switch between these modes to change the characteristics and the performances. Each one has dedicated benefits and usage. This could be for example range, data rate, robustness and symbol rate.

*Table 2 - BLE 5.0 Physical layer comparison [32]*

| | **Physical layer configuration** | | | |
|---|---|---|---|---|
| | ***LE 1M*** | ***LE Coded S=2*** | ***LE Coded S=8*** | ***LE 2M*** |
| **Symbol rate** | 1Ms/s | 1Ms/s | 1Ms/s | 2Ms/s |
| **Data Rate** | 1Mb/s | 500kb/s | 125kb/s | 2Mb/s |
| **Range Multiplier** | 1 | 2 | 4 | 0.8 |
| **Error Control** | CRC | CRC & FEC | CRC &FEC | CRC |
| **PDU Length** | 0-257 bytes | | | |
| **Frequency** | 2400-2483.5 MHz | | | |

*Table 3 - PHYs configuration advantages according to [30]*

| Physical layer configuration | Advantages |
|---|---|
| LE 1M | Compatibility:<br>This mode is the only one available on every BLE anterior version. In addition, this configuration is the only one compulsory on every BLE 5.0 chipset. |
| LE Coded S=2 | Compromise between range and data rate:<br>Thanks to the use of forward Error Correction, this mode increases the range by twice with only a reduction by two of the data rates. This is a compromise between LE 1M and LE Coded S=8. |
| LE Coded S=8 | Range:<br>This mode provides a range multiplier of 4 to allow longer distance use at the expense of a lower throughput (125kb/s max) |
| LE 2M | Strong throughput:<br>This mode enables throughput of up to 2Mb/s at the expense of a range reduction of approximately 20%. |

## 2.2 RANGE

Before the 5.0 version the BLE was not consider enough interesting due to a short range and the need of pairing and a dedicated connection between devices.

The range of Bluetooth 5.0 was improved compared to Bluetooth 4.0. A new PHY layer mode was added to increase this range (LE Coded mode). This improvement is partly due to Error correction with cyclic redundancy check (CRC) and forward error correction (FEC).

Note: see annex 1 for complementary information.

### 2.2.1 PERFORMANCES

Summary of the average range by type of environment.

*Table 4 - BLE 5.0 average range based on [2]*

| Scenario | Average range [m] |
|---|---|
| Outdoor Environment - LOS | 200 – 400 |
| Outdoor Environment - NLOS | 100 – 200 |
| Indoor tests | 40 - 50 |

In *[2]* they use BLE 5 LE Coded (S=8) mode and 0dBm or 9dBm which is bellow ETSI TX power limitations (10dBm). It improves the communications range but with a lower throughput (26 kbps) than with BLE 4.

### 2.2.2 CONSEQUENCES

The range make it possible to use the technology in some use case like the V2VRU, V2I and V2V in cities. But the V2V outside cities and the V2N seems impossible with this technology.

## 2.3 LATENCY

### 2.3.1 PERFORMANCES

Latency – broadcast communication mode = 0-30ms (but more typical settings lead to 0-110ms)

Due to the access mechanism described in §0 (see Figure 3 ), a message can wait for a maximum of *advInterval* plus *advDelay* before being transmitted. The respective minimum for theses parameters is 20ms (but usually set to 100ms) and 3h. Thus, the maximum transmission latency depends on the configured *advInterval* with a minimal value of 30ms.

Latency – connection-based communication mode = Not evaluated for advertisement mode

*Table 5 - Technology latency*

| Type | Value |
|---|---|
| Theoretical | 0-30ms (0-110 typ.) |

## 2.4 CONGESTION

To evaluate the auto interference impact, IMT Atlantique has performed experiments with several BLE devices sending BLE advertisement in the same faraday room. In this test scenario, devices send 10 legacy advertisement messages per second. Note that this experimentation was conducted in a very small area in order to maximise the interferences and the collisions.

In these conditions, the mean Packet Delivery Ratio (PDR) decrease with the number of devices taking the following values:

- 100% with one sending device
- 97% with 5 devices
- 94% with 10 devices
- 92% with 15 devices
- 88% with 20 devices

### 2.4.1 CONSEQUENCES

These values confirm the capabilities of BLE to transmit small messages between several stakeholders in its coverage range.

## 2.5 MOBILITY

### 2.5.1 TESTING CONTEXT

There are still very few literatures on the use of BLE for basic safety ITS service. The testing context in [34] are motorway, line of sight (LOS) and BLE 4.2. The payload is 15 octet which is much smaller than typical safety ITS messages. Ego vehicle

### 2.5.2 PERFORMANCES

In [34] section 3.7.1, tests were performed on motorway and showed that Speed is not too penalizing for the BLE, and it was only with the 4.2 BLE version.
I2V tests were performed at 90km/h and 130km/h.

### 2.5.3 CONSEQUENCES

In these conditions, the limitation factor regarding mobility is rather due to the radio range than the resistance to the effects of speed. Indeed, at 90km/h (25 m/s) and considering a radio coverage of 200m, the coverage only lasts 8 seconds. The effect of speed should be further investigated with longer messages.

Note that this still let room for emergency or awareness messages announcements. Indeed, a typical advertising period for BLE is 100ms, which enables for transmitting up to 80 messages in 8 seconds.

## 2.6 POSITIONING

### 2.6.1 CAN THE TECHNOLOGY PROVIDE A LOCALIZATION? WHAT IS THE PRECISION?

The technology can assist in localization, but since it requires multiple anchors, it should be limited to very small places, such as underground parking. The accuracy of this positioning is between 2m and 5m.

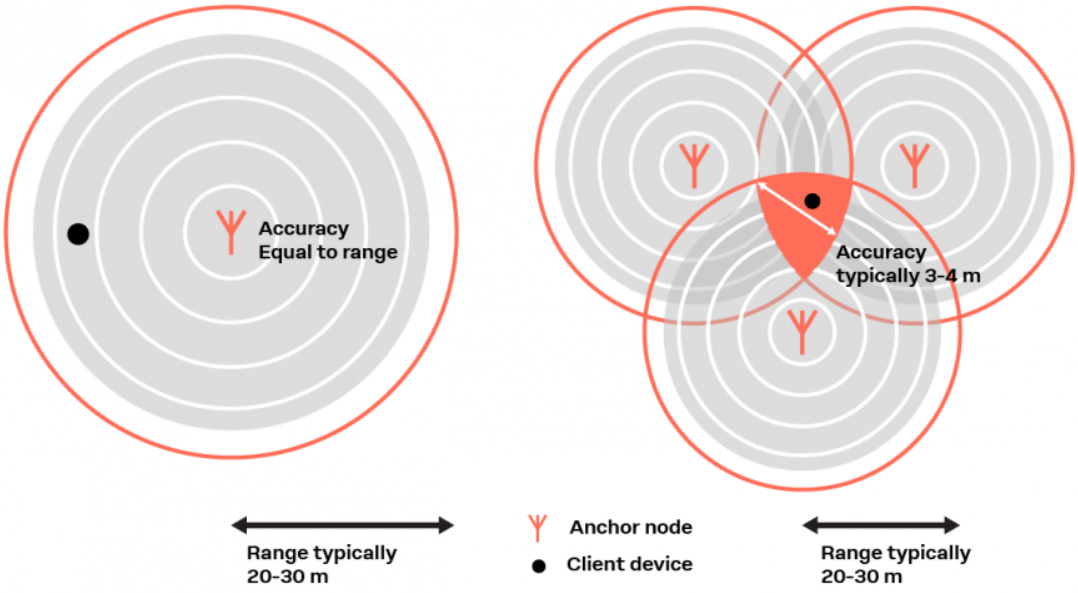


*Figure 4: Positioning capability of BLE*

Bluetooth 5.0 positing requires multiple anchors to have an acceptable accuracy. This means that only an anchor positioned on a car will not be enough to use Bluetooth as a localization technology. Solutions to that are using another technology to locate devices or installing several anchors at strategic points (intersection for example) to allow a good accuracy.

### 2.6.2 How does the technology can improve the precision of the GPS positioning?

Before Bluetooth 5.1 positioning was based on RSSI (Received Signal Strength Indication), which monitors the strength of the radio signal from a source. The RSSI approach is functional, although it is like painting with a broad brush. RSSI only brings distance information, while Angle-of-Arrival (AoA) and Angle-of-Departure (AoD) also bring direction precision. AoA and AoD use the phase of the received signal rather than just its power. AoA and AoD are available in Bluetooth only from the version 5.1, and it will require specific hardware (antenna array, multiple antennas) at least on one side. So is the Time of Flight (ToF) capability, which let estimate the distance between the transmitter and the receiver by measuring the wave travel time between them.

Chip founders released the first developer kits for AoA, AoD and ToF in end 2019. However, there is for the moment a lack of information about the performances of this technology in real conditions and especially in road scenarios. In order to achieve good range accuracy, ToF has to be measured precisely, which can't be done out of the box with cheap Bluetooth Transceivers. Accuracy is to be expected within 2 meters. There is currently no official specification for ToF, so interoperability across chipset vendors cannot be guaranteed.
Bluetooth SIG is in the specification process for the Channel Sounding feature which is expected to be part of the next release in 2023. Range accuracy is expected to be around 50 cm.
First tests performed by IMT Atlantique show that this technology is subjected to the effects of multipath. Furthermore, the physical integration into cars might be complicated by the fact that AoA/AoD require special antenna networks, which require a significant space on-board (typically 10x10 cm) and with a limited observation aperture (typically 90 to 120° for one network).

# 3. Technology Characteristics

## 3.1 SUPPORTED MESSAGES

*Table 6 - V2X messages supported by BLE 5.0*

| Type | Rate | Theoretical size |
|---|---|---|
| Small messages only<br>(max 256 bytes)<br><br>Typically CAM, DENM, SPAT | Typically 10 messages/s<br>(max theoretical: 50 msg/s) | 31 bytes max in legacy adv mode.<br>256 bytes Max using new BLE 5 modes |

## 3.2 COHABITATION AND INTERFERENCES

| Technology's name | Co-channel coexistence [OK] / Interferences [NOK] | Interoperability [OK / NOK] |
|---|---|---|
| ITS-G5 based on IEEE 802.11p | NA | NA |
| PC5 based on 3GPP rel 14 | NA | NA |
| PC5 based on 3GPP rel 16 | NA | NA |
| 4G | OK | NOK |
| 5G | OK | NOK |
| BLE | OK | OK |
| Wi-Fi | OK | NOK |

BLE operates in the 2.4GHz ISM band. Thus, it does not suffer from interferences from ITS-G5, C-V2X or standard cellular communications.

Interferences can however come from other Bluetooth devices (auto-interference) or other devices operating in the 2.4GHz band, which use Wi-Fi in most cases.

Section 2.4 discuss about auto interference and show that its levels are compatible with targeted use cases.

In order to avoid interferences with Wi-Fi, BLE sends each advertisement message on three different channels spread over the 2.4GHz band (Figure 2). In theory, this prevents one single Wi-Fi transmission to interfere with BLE transmissions.

IMT Atlantique has made Wi-Fi to BLE interference measurements in two scenarios:

- Scenario 1 is the worst possible case: a Wi-Fi transmitter is placed just next to a BLE receiver.
  In this condition, nearly all BLE advertisements transmitted on the colliding channel are lost, but transmission reaches a PDR of approximately 75% thanks to the two redundant channels.
- In the Second scenario, a transmission is set up between two BLE devices in an office covered with several Wi-Fi networks covering all the 2.4GHz. But the Wi-Fi devices (computers and AP) are at 2m at least from the BLE devices under test. In these conditions, the PDR of the BLE link typically reaches 97%.

These results show that BLE offer an acceptable interference protection regarding other sources except those behaving as 2.4GHz wide band jammers located at less than 5m from the device.

## 3.3 SECURITY

### 3.3.1 CONSIDERATION OF GDPR

Yes, it is compliant with GDPR requirements.

# CONCLUSIONS

To conclude, BLE is limited for mobility purpose because, today, all the V2X standards and profiles are not applicable to BLE communication. It would not be efficient to use the current standards on the technology and thus, everything needs to be built for the BLE. It might show potential in the distant future.

BLE is well suited for direct short-range (typically 100m) opportunistic communications with limited throughput (up to 250/500kb/s).
In addition, the market penetration of BLE on consumer devices like smartphones makes it a good candidate for Vulnerable Road Users (VRU) like pedestrians or cyclists. Man can imagine that specific Road-Side Units (RSU) can relay communication between these VRU and other V2X devices on specific dangerous places like crossroads, school surroundings, etc. The RSU could relay the BLE messages either in BLE again (to extend range) to translate it to another V2X protocol such as ITS-G5 or C-V2X.

# ACKNOWLEDGEMENTS

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Partners

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# TABLE OF ILLUSTRATIONS

# ANNEX 1: RANGE INDIVIDUALS' STUDIES

The BER (Bit Error Rate) for the Bluetooth is the probability that a transmitted bit will be incorrectly decoded by the receiver. Bluetooth defines a BER of 0.1% as the limit which a receiver must achieve.

| Type | Value [m] | Mode | Link |
|---|---|---|---|
| Maximum range during outdoor tests (still lake) | 750 | Long range (LE Coded) | Link1 |
| Average range during outdoor tests (still lake) | 500 | Long range (LE Coded) | Link2 |
| Maximum range during outdoor tests (parks and semi-open spaces) | 350 | LE 1M | Link3 |
| Average range during outdoor tests (parks and semi-open spaces) | 300 | LE 1M | Link4 |
| Maximum range during outdoor tests (parks and semi-open spaces) [m] | 500 | Long range (LE Coded) | Link5 |
| Average range during outdoor tests (parks and semi-open spaces) | 400 | Long range (LE Coded) | Link6 |
| Average range during indoor tests (shopping centre with lot of Wi-Fi and Bluetooth traffic) | 100 | LE 1M | Link7 |
| Average range during indoor tests (shopping centre with lot of Wi-Fi and Bluetooth traffic) | 130 | Long range (LE Coded) | Link8 |
| Average range during outdoor tests (parks and semi-open spaces) | 430 | LE 1M | Link9 |

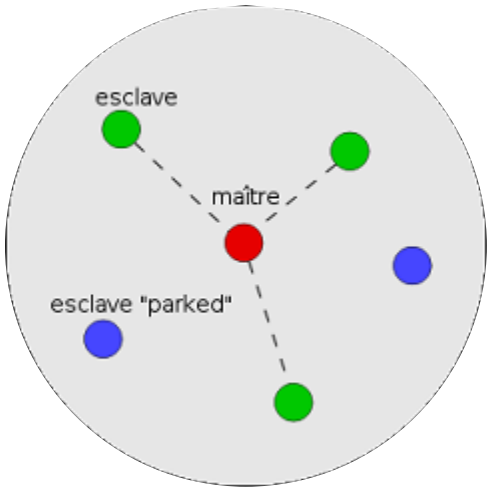
Note: These tests were realised by individuals and not labs.

Summary of the average range by type of environment.

| Scenario | Range |
|---|---|
| Outdoor tests (still lake) | 300 – 600m |
| Outdoor tests (parks and semi-open spaces) | 300 – 400m |
| Indoor tests (shopping centre with lot of Wi-Fi and Bluetooth traffic) | 100 – 200m |

# ANNEX 2: CONNECTION-BASED COMMUNICATION MODE

Master and slave working. A piconet is composed of a device and the other devices around him. A master can connect to 7 slave devices because the logical address is coded on 3 bits (255 slaves possible in parked mod because no physical address).




The master is only connected to a slave at the time, but it switches between different slaves quickly to simulate a connection with every device. It is possible to link multiple piconets thanks to devices doing bridges between them: