Feasability of Bluetooth 5.0 connectionless communications for I2V applications

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***Abstract*— Vehicle communications are one of the pillars of the development of Intelligent Transport Systems. This is a complex scenario, where several types of entities interact with each other, using a range of communication infrastructure. In this area there are several applicable technologies, with different advantages and disadvantages. Therefore, flexible and ubiquitous communication, capable of using any communication type, will allow Smart vehicles to use the most appropriate one to improve traffic movement systems. Although the use of Bluetooth has been considered in this field, it has normally been done in intra-vehicle communications, or if it has been done outside this field, for inter-vehicle communications, it has been done based on standard 4.2 or earlier versions. The Bluetooth BLE 5.0 standard has features that allow the use of this technology in previously unimaginable scenarios; in particular, the increase in range, and greater robustness in communications allowing the analysis of its use as an infrastructure to vehicle network. The preliminary results obtained demonstrate this viability and the potential of this technology in this field.**

Keywords—Bluetooth Low Energy, Internet of Things, Intelligent Transport Systems.

I. INTRODUCTION AND RELATED WORK

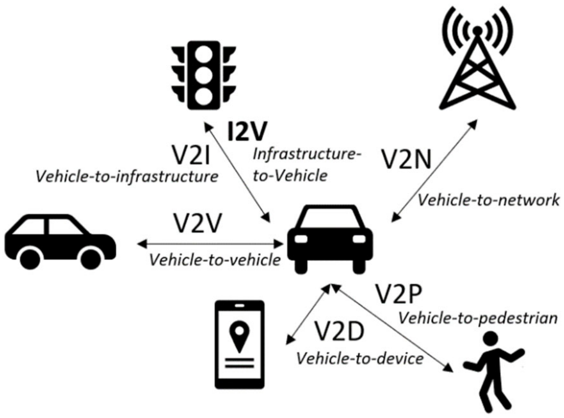

Figure 1. V2X Concept

Vehicle to everything (V2X) technologies are one of the most promising technologies for the short and medium term within Intelligent Transport Systems (ITS) [1], and with more open aspects still to be defined. This technology will change the way information is exchanged between the vehicle and its environment, making information available and accessible, which will change the way people drive. This will offer also important support for automated driving technology. These vehicle communications will make it possible to improve safety and efficiency by improving traffic management, reducing the number of accidents, and reducing pollution [2]. These technologies must be supported by a heterogeneous and efficient wireless communications infrastructure. Within V2X communications, there are different types of communications (see Fig. 1), such as Vehicle to Vehicle (V2V), or Infrastructure to Vehicle (I2V), etc. which will obviously have different requirements [3]. It is considered that V2X applications can be classified in the following categories [4], which generally have similar requirements: Infotainment; Traffic Efficiency; Traffic Safety; Cooperative Driving. Traffic efficiency applications are intended to improve the flow of road traffic, such as intersection timing coordination, congestion information and GPS information. Although some applications in this area may require low-latency and robust network connections, others may require moderate latencies and 1 Hz communications [3]. It is in this context, where Bluetooth 5.0 technology offers an alternative in I2V-V2I environments.

Bluetooth is a widely accepted and extended technology, which does not need infrastructure, and has a high market penetration. It is commonly used in all types of devices and vehicles, and therefore has great potential for use in I2V applications with respect to other technologies such as DSRC (Dedicated Short-Range Communications) [5][6]. One of the first uses of Bluetooth in this context is in intervehicle communications [7], and its robustness in different scenarios such as V2V systems has been analyzed. In [4] different access technologies are analyzed, highlighting Bluetooth as an intra-vehicle infotainment system technology, but discarding it in other areas when considering a 10 meter Personal Operating Space, and the difficulties related to establishing incoming connections with approaching vehicles. However, with Bluetooth 5.0 the range of communications is much higher, and there are connectionless applications where it is not necessary to complete the process of establishing a connection, but only to disseminate information, which makes this technology feasible for this type of application [5] [6]. The use of Bluetooth Communications as an I2V communications network has been analyzed in different scenarios, using Bluetooth 4.0 and connection-based communication [8]. In [9], Bluetooth 4.0 and Zigbee are compared for this type of applications, highlighting the greater stability of Zigbee, although it is a much less widespread technology than Bluetooth, with a lower range and speed [10]. A review of communication alternatives in V2X can be seen in [6]. In [11] the problems of coexistence of Bluetooth and 802.11 are analyzed, limiting the range to 50 meters, but using Bluetooth 2.0 and a power of only 4dBm. In [12], distances of up to 527 meters can be reached while maintaining the connections, although the interference that can be caused by typical objects in cities, such as trees, and which can limit the distance to 95 meters, is also highlighted.

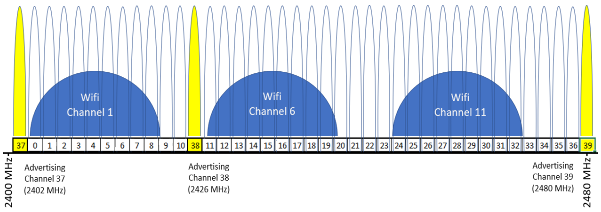

Figure 2 Bluetooth channels

Although networks to support ITS technologies are still under development and being tested [13]. We agree with the authors of [14] that "Smart flexible ubiquitous hybrid vehicle networks based on IoT and 5G communication, which are able to use any type of available communication, is a promising concept to significantly improve the road safety in the future".

This paper discusses the improvements that the use of Bluetooth 5.0 communications can bring in this field. Increased payload extends the range of applications, while LE coding allows for increased maximum coverage range without having to increase transmission power. Section II gives a summary of the characteristics of Bluetooth 5.0, section III specifies the scenario and the different tests carried out, and the paper finishes with section IV, which presents conclusions and proposed future work.

II. BLUETOOTH LOW ENERGY

Bluetooth technology is now widely used for the exchange of information between devices. Originally, this communication technology was created for the exchange of voice and data information between nearby devices, using the 2.4 GHz band. From the Bluetooth version 4.0, the Bluetooth Low Energy (BLE) architecture was also defined, with improvements for the connection of devices that require low consumption, but also with improvements in throughput, range, latency, and security issues. The latest versions of this technology, called Bluetooth 5.0 (and the improvements 5.1 and 5.2) have been designed for the interconnection of Internet of Things (IoT) devices. Among the main advantages in this field of this version with respect to its predecessor (Bluetooth 4.2) is that it can reach a range 4 times higher and allow the length of advertising messages to be up to 8 times longer. These features extend the range of applications where it is interesting to use [5], highlighting the improvements to increase their ability to offer a communication solution I2V. Bluetooth 5 includes two new configuration options for the physical layer, called LE_1M, LE_2M and LE_Coded.

TABLE I. BLUETTOH PHYSICAL LAYER COMPARISON

	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 1 shows the differences between the different physical levels in Bluetooth 5.0. The LE_2M encoding increases the throughput, but at the cost of reducing the range and is more intended for connected applications. LE_1M encoding is compatible with previous versions. In the V2X environment it is interesting to increase the range and improve the robustness of communications. This is where the LE_Coded can contribute to the use of Bluetooth in the I2V domain. As can be seen in Table I, in addition to the cyclic redundancy check (CRC) generated for fault detection, it incorporates a forward error correction (FEC), based on adding redundant bits to the transmitted packet, so that, if the interference suffered is not excessive, the data can be extracted [10].

The Bluetooth link level defines a common packet format for the exchange of advertisements, for connectionless communication, and for the exchange of data in connection-based communication. In connectionless communication, the information is distributed by broadcast on the advertisement payload to all nodes within range. This payload is limited in Bluetooth 4.x to 31 bytes, so only very short messages can be transmitted. For larger messages, the fragmentation and reassembly data can be managed by transmitting multiple advertisements, but this often leads to an overload and increases the probability of error. Of the 40 channels in which the 2.4 GHz ISM band is divided, in the previous versions it was only possible to use the 3 primary channels for advertisement, using the other 37 only for data (See Fig. 2). In version 5.0, we can use those 37 channels also as secondary channels for advertising, using the new PDUs (Packet Data Units) defined. This way, in the primary channels the advertisement is transmitted, with a pointer (AuxPtr) to the data that are transmitted in one of the secondary channels, breaking the 31 bytes limit (although in a standard configuration only 10 of these bytes are useful) of information in the advertisement and setting it to 255. This pointer includes the channel number where the data will be transmitted, so that the receiver knows where to find them. This mechanism results in less competition for the primary channels by transferring the data to the secondary channels. Furthermore, using Bluetooth 4.x the same payload was transmitted three times on different channels, while in Bluetooth 5.0 this data is transmitted only once (see Fig. 3). This has advantages, but also reduces the reliability of communications, although on a physical level and with LE_Codec coding this reliability is increased.

TABLE II. TECHNICAL COMPARISON BETWEEN BLUETOOTH VERSIONS

Version	4.0	4.1	4.2	5.0 & 5.1
PDU Payload	up to 31 bytes			up to 255 bytes
Adverstising Channels	3			3 primary and 37 secondary
Data Rate	1 Mb/s			1-2 Mb/s
Effective outdoor range	50 meters LOS			200 meters LOS

III. TESTBED AND RESULTS

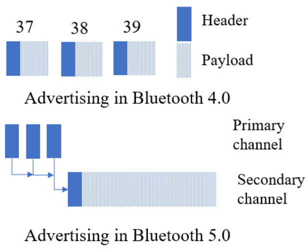

Figure 3 Bluetooth advertising

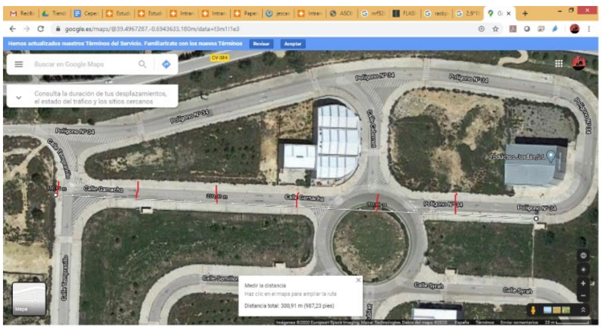

Figure 4 Scenario

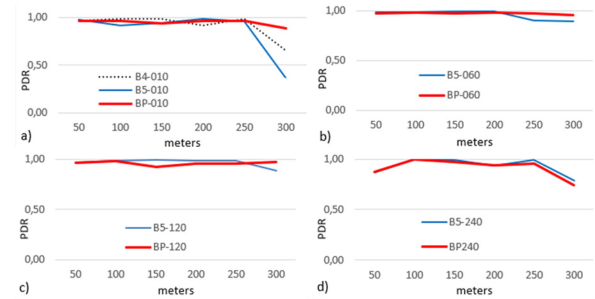

Figure 5 PDR at link level depending on codification and distance

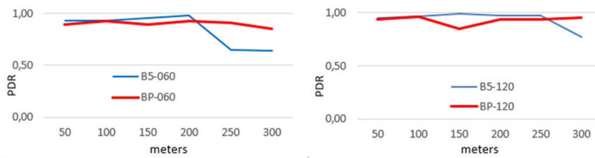

Figure 6 PDR at application level depending on codification and distance

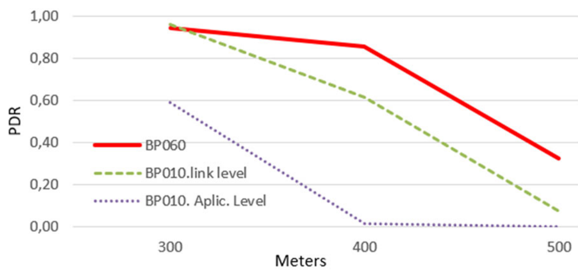

Figure 7 Link and Application successful rate

To simulate an I2V application, a transmitter node was used, which sent information within the advertisement with a determined frequency, and a static receiver node, located at known distances, to evaluate the reliability of these transmissions. Rigado-Nordic nrf52840 DK plates at 8 dBm were used as nodes, capable of implementing BLE version 5.0, also using an antenna with 6 dBm. Figure 4 shows the scenario where the equipment was deployed to perform the tests, marking in red the points where the receiver node was installed, distributed every 50 meters. Given the emergency situation caused by the Covid-19, and the mobility restrictions in which it has been necessary to work in the time planned for these tests, it was not possible to have a scenario where the range could be tested better, limiting these tests to the 300 meters available, enough for I2V applications [15]. In this type of applications, the typical payload goes from 240 bits [9] to a range between 256 and 1024 bits [8, 15] (between 30 and 128 bytes). This represents no more than 128 bytes. In this test the information to be transmitted was assumed to fit into the maximum size of useful information in an advertisement frame, which is 238 bytes in 5.0, and 10 bytes in 4.0. This implies a fragmentation and reassembly of 24 consecutive packets, when 4.0 is used. Packet sizes of 60 and 120 bytes were also used but using the 5.0 encodings as well. The tests used the prefix nomenclature B4, B5 and BP to reference the tests using 4.0 with LE 1M encoding, 5.0 with LE 1M encoding and 5.0 with LE_CODEC encoding with S=8, the only one supported by the hardware used, which has a lower data rate but a longer range (see Tab. I) than the same encoding with S=2. The suffixes correspond to the packet length into which the nearly 240 bytes of payload have been broken down. That is, the endings 010, 060, 120, and 240 fragment the 240 bytes into 24, 6, 2, or no fragmentation. To keep the transmission rate constant in the different tests and using 100 ms. as the minimum time between packets, they are transmitted every 100, 600, 1200 or 2400 ms., which is the advertisement interval of the sender, leaving the scan Interval/window of the receiver at 100 ms. The Packet Delivery Rate (PDR) at the physical level can be seen in Figure 5. When the packet is fragmented into 10 bytes messages, as can be seen in Figure 5.a the success rate at the physical level below 250 meters is quite high. However, at the application level, having to recompose a very fragmented message, the success rates are quite chaotic, and for B4 and B5 it is impossible to recompose a single application packet, while for BP only 6% of the application messages are recomposed. When larger packets are used, the percentage of correct packets at link level is also quite high above 200 or 250 meters, and at application level below 200 meters the rate is also very high (see Figure 6). Above these values, the small difference at link level between B5-060 and BP-060, translates into a significant difference at application level, as these messages are formed by 4 packets. For minor fragmentations (120 and 240), there are hardly any differences.

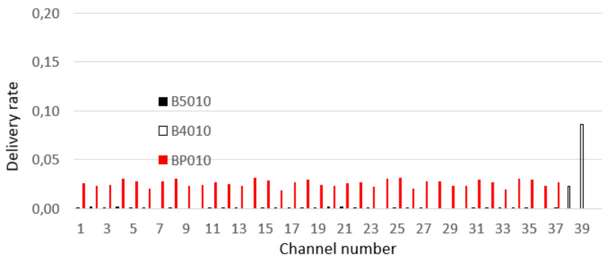

Figure 8 Channel Delivery Rate Distribution at 300 meters

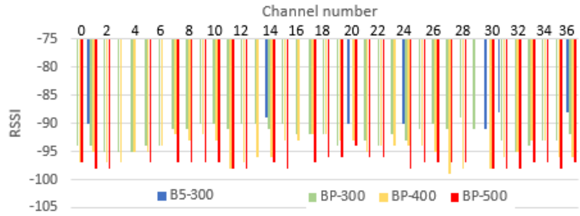

Figure 9 RSSI measured for BP and B5 at 300, 400 and 500 meters

These results demonstrate the viability of using Bluetooth 5.0 in I2V and V2I applications, as they can support the sending of messages with a payload of between 60 and 240 bytes, with an acceptable PDR, however, they have not been able to show the full potential of LE_CODEC S=8 with respect to LE_1M. In order to evaluate this, and after relaxing the containment measures in the country, measurements were taken using a 60 byte payload, sufficient for this type of application, using the three previous technologies, and fragmented into sizes of 10 or directly using 60 bytes. Bluetooth 4.0 has not been represented in Figure 7 since only a few packets reached 300 meters, about 10%, without managing to reconstruct any application message with LE_1M encoding. Using Bluetooth 5.0 LE_1M does not achieve packet transmission either, giving also less than 10% of the Bluetooth 4.0 version. This could explain why using 4.0, the same 10 bytes are sent on channels 37, 38 and 39, reaching 10% of received packets on channels 38 and 39 (See Fig. 8). Using 5.0 LE_1M, that data is sent only once and on one of the secondary channels, reducing the probability to 1%. For longer distances these encodings have not been tested. In this sense, the LE_CODEC S=8 coding, although it also distributes the payload through the secondary channels, the robustness of this coding and the correction of errors means that we get rates of 96% at 300 meters, 61% at 400 meters and 7% at 500 meters. However, with these rates at the application level and for distances of more than 300 meters, it is hardly possible to reconstruct any message (See Figure 7). Without fragmenting the payload, it can only be sent using Bluetooth 5.0. This time, 60 bytes payload messages using LE_1M barely reach the destination for 300 meters. Fig. 9 shows the RSSI measured using LE_1M at 300 meters which has a sensitivity of -93 dBm that few are satisfied for 300 meters, while the sensitivity of 103 dBm [12] of LE_Codec S=8 allows users to transmit successfully in most channels even at 500 meters. Using the LE_Codec S=8 coding we do achieve rates of 94% and 85% at 300 and 400 meters respectively. For distances of 500 meters the results fell to 32% as can be seen in Figure 7. Figure 10 shows the channel distribution of the delivered packets. As can be seen, at 500 meters there are channels that present many delivery problems.

IV. Conclusions and Fututе Work

The potential of using Bluetooth 5.0 in I2V (and V2I) applications has been demonstrated, thanks to the increased range and improved communication robustness achieved with LE CODEC S=8 coding. However, to validate these applications, the study must be able to be carried out with vehicles in motion, and with interference in the normal environment in V2X scenarios with a normal vehicle density. In this next analysis, the use of dynamic blacklist channels should be used to adapt the use of channels in an environment that is expected to change very dynamically.

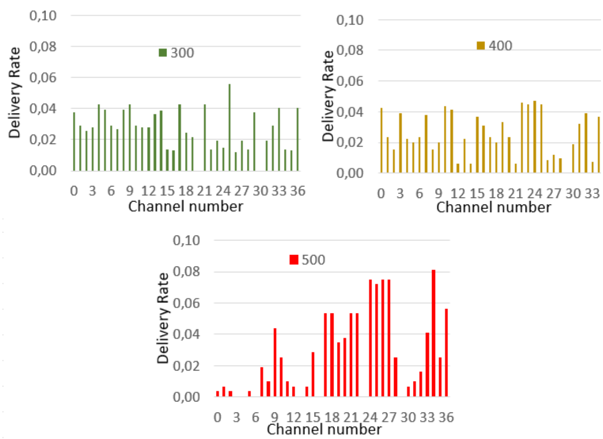

Figure 10 Channel Delivery Rate Distribution for LE CODEC S=8 at 300, 400 and 500 meters.

Acknowledgment

This work has been supported by the project PRYSTINE which has received funding within the Electronic Components and Systems for European Leadership Joint Undertaking (ECSELJU) in collaboration with the European Union's H2020 Framework Programme and National Authorities, under grant agreement No. 783190, and from the "Instituto Valenciano de Competitividad Empresarial" – IVACE. It has also been funded by the MCyU (Spanish Ministry of Science and Universities) under the project ATLAS (PGC2018-094151-B-I00), which is partially funded by AEI, FEDER and EU.

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