Análisis del cumplimiento de Bluetooth 5 con los requisitos de IoT de la UIT

Analysis of Bluetooth 5 Compliance of ITU's IoT Requirements

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Resumen: Bluetooth es una tecnología inalámbrica abierta, de corto alcance y de baja potencia, cuyo objetivo es simplificar la comunicación entre diferentes tipos de dispositivos. Bluetooth tiene cinco versiones, divididas en dos modos de funcionamiento principales, *Classic Bluetooth* y *Bluetooth Low Energy* (BLE). BLE está diseñado para el uso de aplicaciones IoT (*Internet of Things* - Internet de las Cosas). La quinta versión de Bluetooth mejora todas las prestaciones para superar a otras tecnologías que quieren ser la base de las comunicaciones IoT. Bluetooth 5 logra mayor alcance, mayor velocidad de transmisión de datos, soporte mejorado para anuncios y eficiencia energética que las versiones anteriores. La nueva función de topología de malla hace que Bluetooth sea un buen candidato para las comunicaciones de Internet de las Cosas, ya que permite arquitecturas descentralizadas. En este trabajo se realiza una revisión de la versión 5 de Bluetooth. Además, se presentan los requisitos de operación de IoT, basados en las recomendaciones de la UIT (*Union Internacional de Telecomunicaciones*). La contribución de este trabajo es el análisis de las características de Bluetooth 5 para determinar si cumplen o no con los requisitos de IoT propuestos por la ITU. Los resultados del análisis indican que Bluetooth 5 cumple con los requisitos de alto nivel y aproximadamente la mitad de los requisitos de IoT estándar de cada categoría.

Palabras clave: *Bluetooth 5, Internet de las Cosas, ITU, IoT, Tecnología Inalámbrica.*

Abstract: Bluetooth is an open, short-range, and low power Wireless technology, which aims to simplify communication between different kinds of devices. Bluetooth has five versions, divided into two main operation modes, Classic Bluetooth and Bluetooth Low Energy (BLE). BLE is designed for the use of IoT (Internet of Things) applications. The fifth version of Bluetooth improves all the features to surpass other technologies that want to be the base of IoT communications. Bluetooth 5 achieves greater range, higher data transmission speed, improved support for advertising, and energy efficiency than previous versions. The new mesh topology feature makes Bluetooth a good candidate for IoT communications since it allows decentralized architectures. In this work, a revision of the Bluetooth version 5 is carried out. Furthermore, the IoT's operating requirements, based on the recommendations of ITU (International Telecommunication Union), are presented. The contribution of this work is the analysis of the characteristics of Bluetooth 5 to determine whether or not they meet the IoT requirements proposed by the ITU. The analysis results indicate that Bluetooth 5 meets the high-level requirements and approximately half of each category's standard IoT requirements.

Keywords: *Bluetooth 5, Internet of Things, International Telecommunications Union, IoT, Wireless Technology.*

1. Introduction

Bluetooth 5 is the latest version of the wireless Bluetooth technology, whose functionality and characteristics are oriented towards an Internet of Things (IoT) [1]. Among these features, an increase in the data transfer speed stands out, which improves the response capacity and decreases latency in applications. Also, Bluetooth 5 presents a considerable increase in coverage with robust connections. Improvements in Bluetooth announcements are presented, allowing them to transmit richer and smarter data. This version detects and prevents possible interference in the ISM band to guarantee the interoperability of the devices that operate in the IoT [2]. Additionally, mesh functionality is added to Bluetooth that allows the direct connection of devices without a central controller's need. All these features can make Bluetooth the best candidate to act in the complex world of IoT. On the other hand, the International Telecommunication Union (ITU) defines the IoT as a global infrastructure that connects all "things" anywhere and anytime. For this reason, the ITU has established certain IoT performance requirements. It should be noted that Bluetooth 5 has been raised to be a key standard for IoT and that there are not enough official scientific documents that specifically explain the benefits of this new version and how it relates to IoT. For this reason, it is necessary and of interest to make a study of Bluetooth 5 and analyze its characteristics to verify if they comply with the IoT requirements established by the ITU and thus determine if it will be a key technology for the future of IoT.

This work is organized as follows. Section 2 describes the theoretical framework; it consists of a review of basic concepts such as the main features of Bluetooth 5 and IoT concepts. Section 3 summarized other works that include analyses about Bluetooth and IoT. In Section 4 we outline the research approach and methodology, that is, a study of how the characteristics of Bluetooth 5 allow it to comply with the IoT requirements proposed by the ITU in its recommendations. Next, how Bluetooth 5 meets IoT requirements and how it relates to IoT is discussed in Section 5. The Section 6 performs a Bluetooth analysis on an IoT use case, specifically a Smart Home. In Section 7, we summarize the findings of the research. And we finalize the work in Section 8.

2. Background

Bluetooth was developed by the Bluetooth Special Interest Group (SIG), and its first specification published in 1999 was version 1.0b [3]. As of this specification, Bluetooth has constantly been changing and gone through various specifications, reaching the last one published in late 2016. Bluetooth wireless technology is a personal area communication system developed to replace cables that connect electronic devices of different technology. The main aspects that characterize it are the robustness of the link, low power, and low cost. Because of these features, Bluetooth can offer services that allow the connection of devices to exchange various data types [3].

In general, the Bluetooth system is divided into two subsystems: Bluetooth Controller, groups the Radio, the Baseband, the Link Management Protocol (LMP) and is referred to as Bluetooth Hardware or Bluetooth module. Bluetooth Host encapsulates the higher layer protocols, the main one is the Logical Link Control and Adaptation Protocol (L2CAP). Additionally, to the Host can access the Controller's capabilities, a physical standard interface is defined, called the Host-Controller Interface (HCI). The HCI interface is optional to use and guarantees interoperability between subsystems when they are not integrated into the same device.

2.1. Bluetooth 5

Bluetooth 5 was released on December 6, 2016, and like the previous version, it is geared to operate in IoT environments. Among the main improvements that Bluetooth 5 presents, there is an increase in speed and range, better performance of announcements, increased transmission power for LE, further decreases interference in the ISM band, and mesh networks are implemented in Bluetooth [5]. For this version, the two forms of the Bluetooth system are maintained: Basic Rate (BR) and Low Energy (LE). Both systems include device discovery, establishment, and connection mechanisms between devices, see Figure 1.

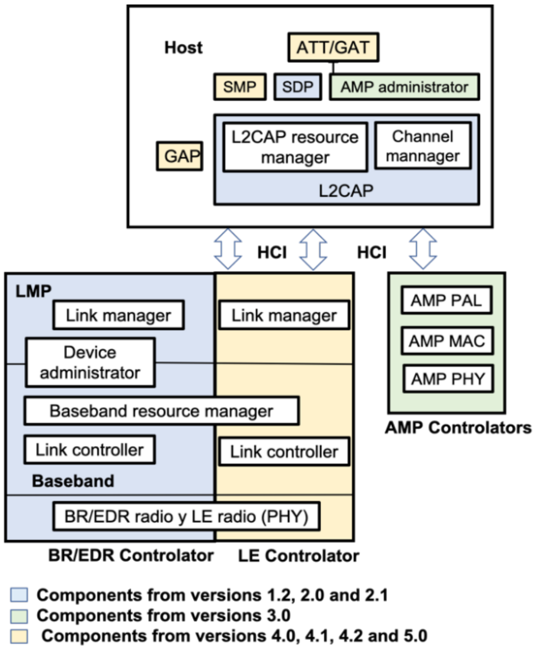

Figure 1. Bluetooth 5 framework.

The Bluetooth system consists of a Host and Controller, which maintains communication through the Host-Controller Interface (HCI). The drivers are BR/EDR, LE, and AMP, and they work the same way as the predecessor version. The BR/EDR and LE controllers operate in the 2.4 GHz ISM free band using a frequency hopping transceiver to combat interference and signal fading. The AMP driver is secondary and works once an L2CAP connection has been established through the BR/EDR physical layer. The physical channel is subdivided into units of time known as events. Data is transmitted between LE devices in packets that are positioned at these events. There are four types of events for Bluetooth version 5, these events are announcements, extended announcements, periodic announcements, and connection [6]. Unlike the previous version, the announces channel is divided into primary and secondary. The primary channel is the set of three channels uniformly distributed in the LE frequency spectrum. In contrast, the secondary channel is a set of 37 physical channels that are the same LE channels used by the data channel [6].

Bluetooth 5 introduces a Slot Availability Mask (SAM), which allows two devices to indicate the available time intervals for transmission and reception. With this, Bluetooth controllers can refine their BR/EDR time intervals and improve the general performance by detecting and preventing edge interference from the 2.4 GHz ISM band and the neighboring LTE band [6]. For the BLE system, SAM is not available. However, a Bluetooth mechanism called Channel Selection Algorithm 2 (CSA2) can help with frequency hopping in environments susceptible to multipath fading. Another essential feature of Bluetooth 5 is that it supports mesh topology. This attribute, known as -Bluetooth Mesh Networking- is a protocol adopted and incorporated into the Bluetooth 5 specification through an Addendum [7] in July 2017. With this functionality, Bluetooth can establish communications between devices without connection to the central device, as a star topology. Mesh capacity is thought for creating large-scale device networks and is ideal for building automation, sensor networks, and other IoT solutions where tens, hundreds, or thousands of devices need to communicate reliably and securely.

Bluetooth Mesh Networking is based on BLE and uses a flooding technique for message transmission; this technique is a reliable and straightforward way of message transmission for low power wireless mesh networks. Therefore, Bluetooth Mesh Networking meets the reliability, scalability, and performance requirements of the commercial and industrial markets [8].

With each new version or update that Bluetooth SIG has released, Bluetooth's features have increased and differentiated one from the other. Bluetooth has been developed in several versions and from version 4, which incorporated the LE controller, two Bluetooth modes were defined, which are presented below:

- Classic Bluetooth covers versions 1-3, and its architecture includes the BR/EDR controller and optionally, the AMP controller. It is also known commercially as "Bluetooth" [9].
- Bluetooth Low Energy covers versions 4-5, and its architecture is the LE controller. It is also known commercially as "Bluetooth Smart" [9].

The modes are similar but not compatibles, so if a device wants to have all the features that Bluetooth offers, it must support both modes (Dual Mode). The dual-mode has the characteristic of having BR/EDR and LE controllers in its architecture; it is also known commercially as "Bluetooth Smart Ready".

2.2. Internet of Things (IoT)

Nowadays, with mobile internet services and the deployment of higher-speed mobile networks such as 4G (LTE), users can connect to the Internet from almost any location. They can also access systems at any time because connectivity is always active. The next step in this technological revolution is to connect inanimate objects to communication networks, resulting in the emergence of the Internet of Things (IoT). From the technical point of view of information and communication technologies (ICT), through the interconnection of physical and virtual objects, they allow offering advanced services such as remote telehealth provision and the implementation of fitness devices as care preventive [10]. As shown in Figure 2, IoT adds the dimension "communication with any object" to ICTs, which already offer users the ability to connect anytime, anywhere.

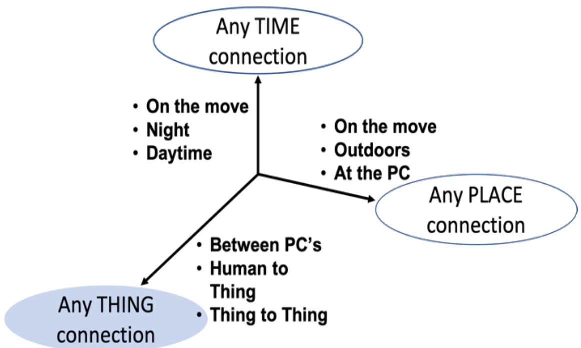

Figure 2. Dimensions of the Internet of Things [11].

With this new dimension, the global communications network will not only consist of humans and electronic devices but also all kinds of inanimate objects. These objects may communicate with other things. For example, refrigerators with grocery stores, laundry machines with clothes, tags implanted with medical equipment, and vehicles with stationary and moving objects. Depending on the IoT context, objects can be of two types: physical and virtual. Physical objects exist in the physical world, and they can be detected, acted, and connected. In contrast, virtual objects exist in the world of information and can be stored, processed, and accessed. It is worth mentioning that the devices in IoT must meet the minimum requirement of having the communication capacity [10].

3. Related work

Other works have reported analyses of the functionality of Bluetooth on IoT. In [1], the authors mentioned that Bluetooth needs to reduce power consumption to be suitable for M2M and IoT applications so that it can be used in battery-powered devices for more extended periods or even the lifetime of the device. The Bluetooth Special Interest Group (SIG) introduced Bluetooth Low Energy (BLE) to achieve a more efficient power consumption. BLE was first specified in Bluetooth 4.0 and further improved in Bluetooth 4.1. The authors in [12] presents future IoT scenarios and use cases that justify the push for Bluetooth 5. Also, a set of new technical features included in Bluetooth 5.0 are presented and compared with other low range wireless technologies. The work of [13] presents a hybrid network among recent Bluetooth and Wi-Fi technologies to provide the IoT applications. Considering that Bluetooth low energy (BLE) works with the minimum amount of power and data rate, sufficient to handle the IoT applications. Jeon et.al. in [14] analyze how new challenges and opportunities have arisen to accommodate IoT development demands. Recognizing the potential in Bluetooth Low Energy (BLE) beacons, this paper reviews different aspects of BLE beacons for their use in IoT applications. The authors in [15] the Battery life for IoT sensors using Bluetooth LE technology have been investigated. The result shows that the incremental change in transmitter power consumption and device active time significantly affects battery life. The work can be used to choose energy-efficient modulation scheme for IoT devices having Bluetooth capabilities. The research in [16] aims to specify the controlling of home appliances and building a smart home system using Bluetooth as a communication protocol. The authors proposed a system that receives the command sent over Bluetooth which is connected to a microcontroller through an interface. From this it is possible control and manage home appliances and devices at our need. In [17], the authors develop comprehensive system-level tool for simulating BLE 5, focusing in a new physical (PHY) layer from networking perspective by analyzing end-to-end delay, battery life time, packet error rate and throughput in open office environment. Its goal was investigating the scalability of the network for different PHYs. These researches introduce some applications or are focus in some special issues of the Bluetooth applied to IoT. In other side, in this work we present concretely the IoT's operating requirements, based on the recommendations of ITU (International Telecommunication Union). The main characteristics of Bluetooth 5 are analyzed to determine whether or not they meet the IoT requirements proposed by the ITU.

4. Methodology

Improvements to Bluetooth 5 focus on increasing Bluetooth functionality for the IoT. Enhancements include increased range and speed of data transmission, ad extensions, improved interoperability and coexistence with other wireless technologies, and functionality of the Bluetooth mesh topology.

4.1. Internet of Things (IoT)

Version 5 introduces a new PHY, which transmits data at a symbol rate of 2 Msym/s, resulting in a nominal data rate of 2 Mbps (LE 2M). In addition to transferring more data, the time to transmit and receive data is reduced, which translates into less energy consumption. Doubling throughput with low power consumption will allow applications to provide faster data transfers for use cases such as streaming data collected from a sensor over days. It also improves latency and responsiveness for applications working in the area of medicine and security systems. For Bluetooth 5, the modulation speed has two possibilities. The first option is 1 Mbps as Bluetooth 4.2, and the packet format and throughput are also similar. The second option is 2 Mbps with a difference in the size of the preamble (increases from 1 to 2 octets). As the modulation speed increases, the duration times of the packets are modified. Table 2 summarize a comparison between Bluetooth LE versions. The Throughput (*Thr*) in version 5 is obtained as following:

$$Thr = \frac{251 * 8\ bits}{(150 + 1064 + 150 + 44)\mu s} = 1.43\ Mbps \quad (1)$$

4.2. Improved range (4x)

A common term used to describe the range capability of an RF system is the “Link Budget”. The link budget is the ratio of the transmit power to the receiver sensitivity level, which is the receiver’s ability to pick up the transmitter signals [18]. As the link budget is defined, the range can be improved in two different ways. The first way would be to increase the transmission power, but this is not feasible since it would increase energy consumption, and the regulations imposed by the telecommunications entities would not be satisfied. Bluetooth 5 achieves this goal by incorporating physical layer coding (PHY) schemes and reducing transmission speed.

Table 2. Comparison between Bluetooth LE versions

	Symbol rate (Msym/s)	PDU length (B)	Payload length (Bytes)	Minimum packet time	Maximum packet time	Maximum throughput (Mbps)
BT 4.0/4.1	1	0-31	27	80 μs	328 μs	0.305
BT 4.2	1	0-255	251	80 μs	2120 μs	0.8
BT 5.0	2	0-255	251	44 μs	1064 μs	1.43

4.3. Extensions in announcements (8x)

Bluetooth announcements were introduced in version 4, and it is a mobile marketing method for delivering content such as messages, information, or ads to mobile devices. Beacons are an essential use case for Bluetooth LE ads. A Beacon BLE is a small wireless device that periodically transmits LE announcement packets to all the devices around it, does not accept a response, and does not establish a connection. The transmitted information can be received and interpreted by an application on a Smartphone or a Wearable. Furthermore, to information from the Beacons, additional information is perceived, such as the strength of the receiving signal and the signal's strength at a distance of one meter. The latter is interesting to estimate the distance and with this to know the location of the users. An example of using Beacons could be when merchants send exclusive offers to users based on their location and indoor route location [12]. There have been some significant changes to the way announcements can be made in Bluetooth 5, compared to Bluetooth 4. New PDUs related to announcements, scanning, and connection have been added to the Generic Access Profile (GAP). These changes allow more significant amounts of data to be delivered in offline scenarios, for announcements to be deterministic, and for multiple different sets of announcements to be broadcast, reducing duty cycle and contention. With this, the beacons will transmit more advanced and intelligent information that can lead to the development of new applications for users.

4.4. Interoperability and coexistence

Bluetooth devices operate in the 2.4 GHz ISM free band, so they share this band with other technologies, including W-LAN, cordless phones, and microwave ovens. The ISM band is also close enough to other frequency bands that Bluetooth devices can interfere with by other technologies like LTE and WiMAX [18]. Thus, the Bluetooth specification supports a variety of features that help minimize interference with other devices and technologies. In general, the types of solutions are derived from techniques such as frequency division, time division, and time alignment. The latter consists of aligning all activities in the time domain to optimize performance by avoiding conflicting activities. For example, it can have multiple transmissions and receptions but cannot transmit and receive simultaneously [6]. The arrival of Bluetooth 5 brought with it a host of critical updates, such as increased range, faster speed, and increased ad capacity, but it also provides better interoperability and coexistence with other technologies, such as LTE. A new feature, available only for BR/EDR, called the Slot Availability Mask (SAM) enables Bluetooth to be a good neighbor to LTE, staying away from channels next to a channel on which LTE is broadcasting. These features help improve coexistence and interoperability in a crowded spectrum environment [18].

4.5. Higher energy efficiency

The improvements in range and speed that Bluetooth version 5 implements, could imply a higher power consumption. However, thanks to smart design, such as the new way the signal is modulated and the way the frequency spectrum is used, Bluetooth 5 uses fewer power resources. In fact, in the best case, the power consumption is reduced by about twice that of Bluetooth version 4.2 [12]. It is relevant to note that Bluetooth needs to be as good or better than IEEE 802.15.4 (ZigBee) solutions to become a competitive technology within IoT environments. For this reason, Bluetooth 5 has introduced new transmission power classes for Bluetooth LE, see Table 3. When selecting a wireless standard for battery-powered IoT applications, providing the same amount of data at half the power is a significant advantage. Besides, infrastructure costs are also reduced, as no access points or routers are required. Consequently, Bluetooth tends to be more efficient in battery life than Wi-Fi and will enable the manufacture of small and robust IoT devices for consumer and industrial applications.

Table 3. Bluetooth LE device classes.

Class	Maximum power	Minimum power
Class 1	100 mW (20 dBm)	10 mW (10 dBm)
Class 1.5	10 mW (10 dBm)	0.01 mW (-20 dBm)
Class 2	2.5 mW (4 dBm)	0.01 mW (-20 dBm)
Class 3	1 mW (0 dBm)	0.01 mW (-20 dBm)

4.6. Bluetooth Mesh

The mesh allows a “many-to-many (m: m)” relationship to be established between wireless devices. Also, devices can relay data to others, not in the direct radio range of the source. In this way, mesh networks can span extensive physical areas and contain large numbers of devices [8]. Due to the benefits of mesh topology, Bluetooth SIG sought ways to include mesh networks into Bluetooth and was accomplished by releasing the Bluetooth Mesh 1.0 specification in July 2017 and adding it to the Bluetooth 5 specification via an Addendum [7]. Bluetooth Mesh defines a managed flooding-based network, which uses broadcast channels to transmit messages so that other nodes can receive messages and relay them, thus extending the range of the original message. This means that messages are not sent via a specific route; instead, all devices in range receive messages and relay the message to all other devices within range. Any device on a mesh network can send a message anytime as long as enough devices are listening and transmitting messages.

5. Analysis of IoT requirements achieve by Bluetooth

The ITU-T Y.2060 [10] and ITU-T Y.2066 [19] recommendations set out the requirements for IoT operation [1]. These are classified into high-level requirements and standard requirements; the latter split into non-functional and functional requirements. Functional is classified as application support, service, communication, device, data management, security, and privacy protection requirements. Considering that Bluetooth is a specification that, according to the OSI model, corresponds to the link layer and physical layer, it will proceed in this section to determine if the new or updated features of Bluetooth 5 meet these requirements above. At the end is a compilation of all the requirements that Bluetooth 5 meets.

5.1. IoT requirements and improved transmission rate

Bluetooth 5 increases data transfer from 1Mbps to 2Mbps without increasing power consumption. By duplicating the amount of data that devices can transfer, Bluetooth 5 reduces the time required to transmit and receive data. This increase facilitates quick and reliable firmware updates for mobile devices. Besides, it allows fast loading of data collected from a sensor from days and also allows wearable devices to synchronize with twice the speed. Firmware updates, which in addition to providing new functionality, often provide bug fixes and security enhancements that help protect users, businesses, and industrial systems [20]. The increase in data rate will allow to initiate and to complete a quick firmware update. Another essential use case is its application to the human body, where medical, sports, and exercise devices are becoming increasingly sophisticated and now often measure multiple dimensions of the human body more frequently and with greater precision. There has also been an increase in devices that act as sensors that collect information, especially in fields like lifestyle analysis. Here, the user will use a sensor for several days and then transfer all the accumulated data to another device, such as a smartphone or computer. Considering the aspects as mentioned earlier, and the high-level requirements of IoT, such as ensuring compatibility and high-level security, the increase in data speed allows Bluetooth 5 to meet the following high-level requirements:

- Since every connected object, high-level security is vulnerable to threats of confidentiality, authenticity, and integrity of data and services. Guarantee the protection of the owners' privacy and users of the objects that intervene in the communication. **Justification:** Increased speed helps keep security up-to-date because firmware updates will be fast and reliable.
- Offer services related to the human body through the acquisition, communication, and processing of data related to the human body's static characteristics and dynamic behavior. **Justification:** With a higher speed, devices that monitor the human body will obtain information quickly and accurately, guaranteeing the reliability and security of these services.
- Guarantee compatibility between heterogeneous systems that supply various types of information and services. **Justification:** Connections and reconnections between devices of different technology are made immediately, with a higher speed.
- Ability to manage objects and applications to guarantee the regular operation of the network. **Justification:** The network administration will be more comfortable with immediate connections and obtaining the information quickly, which is obtained at a higher speed. This will allow remote monitoring, control, and configuration of devices.

5.2. IoT requirements and enhanced scope

The long-range LE feature of Bluetooth 5 can quadruple the range and offer robust and reliable connections. This means that it can have coverage throughout the home and construction and new use cases for outdoor, industrial, and commercial applications. These ranges can be achieved while maintaining the low energy consumption of Bluetooth low energy. Also, it would be easier to move around with a portable device without service interruption. However, the extended range has a shortcoming, since to achieve more range, it is overloaded with redundant information to the payload, which causes the transmission speed to decrease. The improved range of Bluetooth 5 is based on error correction, a function that Bluetooth 4 does not perform, by implementing an encoded physical layer (LE coded). Error correction has the great advantage that data can be correctly decoded at a lower SNR and thus at a greater distance from the transmitter. With error correction, the data no longer needs to be retransmitted by the receiver. Considering the aspects mentioned above, it follows that the increase in range allows Bluetooth 5 to meet the following high-level requirements:

- Support for location-based capabilities, since communications and services object-related, will depend on the location of objects or users. **Justification:** Location-based services can be deployed without problems, as all devices and users can move around a broader area without losing service.
- Guarantee compatibility between heterogeneous systems that supply various types of information and services. **Justification:** The connection between devices of different techniques will be strong, without interruptions, and at a greater distance, thanks to the error correction features of Bluetooth 5.
- Ability to manage objects and applications to guarantee the regular operation of the network. **Justification:** With an improved scope, the management of all devices will be easier since fewer central computers are needed to collect information. This will allow remote monitoring, control, and configuration of devices from anywhere.

5.3. IoT requirements and extensions in announces

One of the main areas for improvement in Bluetooth 5 is how Bluetooth announcements work, and the new specification contains significant updates to beacon's capabilities compared to the previous version. These improvements include an increase in ad packages, new ad PDUs, periodic ads, the ability to send ad data blocks, and increased channels for ad delivery. Bluetooth beacons are a critical use case for Bluetooth advertisements. Bluetooth 5 provides the foundation for creating next-generation beacons, which will allow much more productive and smarter data sets to be broadcast, rather than just an ID or URL. The increased capacity will also drive the next generation of “offline” services that beacons use, such as location/proximity services, discovery services, route location services, and asset tracking services. As the name implies, in an offline service, the devices do not connect as they pass by broadcasting (broadcaster or advertiser) or just listening (observer). A practical example of these services could be a vending machine or refrigerator broadcasting its location ID, temperature, stock level, battery level, number of times the door has been opened, and other maintenance indicators at the same time. Considering the aspects above, it follows that the extensions in the advertisements allow Bluetooth 5 to meet the following high-level requirements:

- Guarantee compatibility between heterogeneous systems that supply various types of information and services. **Justification:** Devices that use Bluetooth advertisements can be placed almost anywhere, for any application, and connect to most electronic devices. This ensures compatibility between different systems.
- Connectivity based on object identification. Support for location-based capabilities, as object-related communications and services, will depend on the location of the objects or users. **Justification:** The increase in the ads' capacity allows the sending of more information, such as their location and identification. This thus opens up a range of location-based services, such as tracking anything.
- Ability to manage objects and applications to guarantee the regular operation of the network. **Justification:** Devices that use ads are generally small and easy to manage, as they will send more detailed information such as its location, thanks to the new ability of ad packages. This allows remote monitoring, control, and configuration of the device.
- Since every connected object, high-level security is vulnerable to threats of confidentiality, authenticity, and integrity of data and services. Guarantee the protection of the owners' privacy and users of the objects that intervene in the communication. **Justification:** Beacons only broadcast advertisements to all devices around them, so they do not collect personal information from users, thus ensuring their security and privacy.

5.4. IoT requirements and interoperability

Bluetooth 5 made some changes to help improve coexistence with other radio technologies on devices such as smartphones. Bluetooth uses the 2.4 GHz ISM band, which is adjacent to the Mobile Wireless Standards (MWS) bands, such as those used for LTE. There is a possibility of interference between the two systems since one system is receiving information while the other radio is transmitting. Bluetooth 5 introduces a system called Slot Availability Mask (SAM), which allows Bluetooth to indicate the availability of its time slots and optimally synchronize with the use of adjacent MWS bands. It should be taken into account that Bluetooth shares the frequency band with Wi-Fi, so since previous versions, it has established mechanisms to avoid interference, such as the AFH method, which avoids the use of the same channels as Wi-Fi. Bluetooth 5 improves on the existing capability that bypasses channels used by Wi-Fi. Therefore, it is concluded that interoperability improvements allow Bluetooth 5 to meet the requirement that "guarantees compatibility between heterogeneous systems that provide various types of information and services". This is because the introduced features make Bluetooth a good neighbor with adjacent technologies like LTE and help decrease interference in the ISM band.

5.5. IoT requirements and energy efficiency

The improvements that Bluetooth 5 implements, in principle, would imply that the devices consume a more significant amount of energy. However, this turns out to be the opposite, as Bluetooth 5 uses fewer power resources due to its efficient use of the frequency spectrum and how information is modulated; the power consumption is lower than the previous version of Bluetooth [12]. In the IoT requirements presented in the ITU recommendations, there are no requirements related to energy efficiency. However, it should be noted that this aspect is of utmost importance for the implementation of IoT applications since devices will be needed every smaller and smaller that consumes the least amount of energy.

5.6. IoT requirements and Bluetooth mesh

The new mesh capability enables many-to-many (m:m) device-to-device communications and is optimized for creating large-scale device networks. It is perfect for building automation, sensor networking, asset tracking, and any solution that requires tens, hundreds, or thousands of devices, especially Beacons, to reliably and securely communicate with each other. The Bluetooth mesh meets the reliability, scalability, and security requirements of the commercial construction and factory automation markets [8]. It also provides interoperability so that products from different vendors around the world work together. Based on the features above, incorporating the mesh topology enables Bluetooth 5 to meet the following high-level requirements:

- Guarantee compatibility between heterogeneous systems that supply various types of information and services. **Justification:** The Bluetooth mesh guarantees compatibility since it allows the connection of thousands of devices with different functions, such as controlling the lighting system using Bluetooth sensors.
- Automatic networks support in order to adapt to different communication contexts, applications, numbers, and types of devices. **Justification:** The Bluetooth mesh allows thousands of devices to communicate with each other, making it a scalable and automatic network adapted to the user's needs.
- Support for location-based capabilities, since object-related communications and services, will depend on the location of objects or users. **Justification:** Beacons configured in a mesh, will allow the development of a variety of location-based applications, such as tracing factory assets.
- Since every connected object, high-level security is vulnerable to threats of confidentiality, authenticity, and integrity of data and services. Guarantee the protection of the owners' privacy and users of the objects that intervene in the communication. **Justification:** The Bluetooth mesh defines security features in its architecture designed to address companies' security problems implementing large-scale wireless device networks. For example, encryption and authentication are performed at the network and application layers [21].
- Ability to manage objects and applications to guarantee the regular operation of the network. **Justification:** Bluetooth mesh allows easy management of devices and services, due to its ability to send messages via flooding. This allows remote monitoring and control of devices.

6. Analysis of Bluetooth 5 in general IoT use case

The enhancements introduced by Bluetooth 5 are designed and manufactured precisely to encourage the spread and adoption of the new standard in the IoT world. For this reason, this section will proceed to analyze whether Bluetooth 5 is capable of supporting IoT applications and requirements in a Smart Home use case in which IoT will have a high impact.

A Smart Home is one in which devices can communicate with each other, their environment, and the Internet. In the smart home, the person interacts with the home through electronic devices and sensors, which can be connected to the Internet to perform the house's functions according to the user's needs [12]. An example of a smart home is shown in Figure 3 and can include Bluetooth sensors to control various aspects such as temperature, lights, doors, and windows to be deployed throughout the home. Also included are electronic devices, smart appliances, and smart security systems (motion sensors, monitors, cameras, and alarm systems). Next, we will proceed to describe the services and functions that the smart home could have.

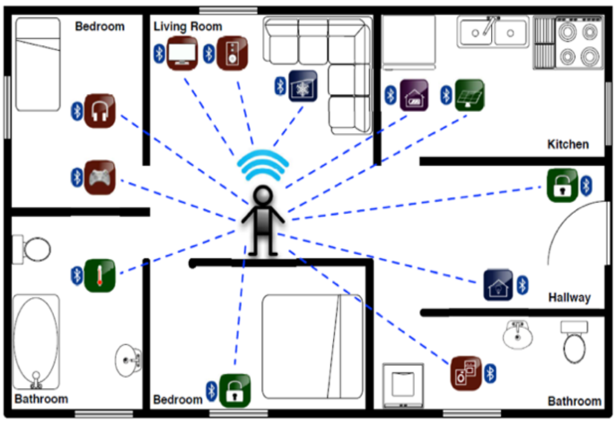

Figure 3. Smart home example.

In the bedrooms, various devices and functions of the house will be controlled by a computer or voice commands. The closet may have a small touch screen through which can access the Internet and look at clothing catalogs. Appliances like washing machines, kitchens, microwaves can be activated remotely or automatically when they detect a nearby presence. They can also have complementary functions such as screens to automatically search recipes online, browse the Internet, or search for effective washing methods. The fridge can be connected to the Internet, have a screen, have a sensor system to detect if it is missing any food, and manage expiration dates, nutritional information, and recipes for cooking stored products. The heating can be started remotely or automatically regulated according to the family customs [12]. All entertainment devices, such as speakers, televisions, and game consoles, will be connected to the Internet to increase users' fun experiences. It can also have an intelligent safety system for identity recognition, surveillance, and monitoring areas of interest using sensors and cameras. Users can turn light on and off any part of the house from anywhere, automatically or controlled by sensors [12]. The gardens can be watered depending on the time or the availability of water. In addition to that, all doors and windows will have sensors for automatic or remote control. Sensors monitor electrical, gas, and smoke installations to warn residents of any signs of a problem that may arise [12].

Table 4. IoT services that Bluetooth 5 can achieve.

IoT services	Cause
Smart lighting.	With Bluetooth sensors configured with the Bluetooth 5 mesh function, home lighting can be properly managed.
Automation of blinds, windows, and doors. Control and monitoring of alarms.	Using Bluetooth sensors, it can automate blinds, windows, doors, and control alarms and air conditioning from anywhere in the house, thanks to the improved range provided by Bluetooth 5.
Air conditioning control.	Besides, communication is much faster, thanks to the higher speed of the connection.
Control and management of energy.	With the faster data transfer rate of Bluetooth 5, all Bluetooth equipment’s power consumption is reduced. In addition to that, Bluetooth devices are designed to consume little energy.
Irrigation control in the garden.	The installed sensors for irrigation can be configured in mesh to increase efficiency, and thanks to the improved Bluetooth range, irrigation can be controlled from anywhere in the house.
Control and diagnosis of home appliances and entertainment devices.	With the improved range of Bluetooth 5, it is possible to control and manage all home appliances and entertainment devices from anywhere in the home. Also, with the increased speed, the connection of devices can be established more quickly, as well as the software updates will be faster.
High-level security.	With the faster speed, security device software updates will be more agile, thus preventing intrusion from outsiders. Also, Bluetooth encrypts messages with AES.
Easy house management through a single device.	The improved speed and range of Bluetooth 5 allow the administrator to control and monitors all devices quickly and easily from anywhere in the house.

With the approximate range of up to 4 times greater than the previous version, Bluetooth 5 will allow the control and management of devices and applications to have an extended and more powerful connection so that users can control the home from anywhere in the house. A 100% increase in speed, without increasing power consumption, will allow faster data transfers in smart home applications, increasing responsiveness, and decreasing latency. One of the most critical Bluetooth 5 is the mesh network that will allow Bluetooth devices to connect in networks that can cover the entire home, allowing for home automation applications such as smart lighting.

7. Analysis of IoT requirements achieve by Bluetooth

When the Bluetooth SIG launched the Bluetooth 5 standard, its primary goal was to make the technology best suited for IoT applications. This was achieved when it added to its specification, the mesh network functionality, which together with the other improvements (broader range, faster data transfer, and the ability to coexist with other technologies), will allow Bluetooth 5 to be useful in the development of applications from industrial systems to the use of Beacons, home automation and smart cities. The Bluetooth mesh will allow a smartphone or PC to communicate with everything on the network without having to interact with a central hub, saving cost and complexity. It can also implement functionalities in which a person's action automatically activates other devices through the mesh. For example, when a person comes home and activates a smart door lock, the Bluetooth mesh could automatically activate the lights, thermostats, and music player.

The Bluetooth Mesh and Bluetooth 5 itself will demonstrate their usefulness in Industrial IoT (IoT) applications. Such is the flexibility of the Bluetooth mesh that, in addition to controlling lighting, air conditioning, and security, the same mesh can facilitate machine-to-machine (M2M) communication, machine status monitoring for maintenance, asset tracking, energy use and much more. Increased range is desirable for any communication application, but is particularly crucial in-home automation environments. Using coding schemes, Bluetooth 5 has allowed an increase in range of up to 4 times compared to the previous version, without increasing the maximum power output. This makes it possible to have coverage throughout the house; it also opens up new possibilities for outdoor applications such as automatic parking meter stations, utility metering. Increasing the mesh and range network also impacts Bluetooth Beacons, which are small devices that send concise messages, without the need for a connection between the beacon and the device. Since the data is minimal, the RF output power is deficient, and the power consumption is minuscule. Beacons are cost-effective, easy to deploy, and incredibly flexible devices, and with the advanced features of Bluetooth 5, their potential increases dramatically.

Bluetooth 5 also increases the beacon's message length from 31 to 255 bytes, so it can transmit messages with more information, such as a URL, telemetry data, or a text message long enough to convey useful information. Increasing capacity will also drive the next generation of offline services, in which devices do not connect, as one only sends information, and the other only receives the information and processes it. With these characteristics, beacons become an interesting bet for retailers and organizations such as museums, which could send notifications with details about a work of art to the visitor. They can also be used for positioning and navigation, tracking virtually anything (including people), and automatic trade show attendee registration, among many other applications. Furthermore, the security provided by beacons is beneficial as they do not collect personal information from users. Bluetooth 5 increases its maximum data rate from 1Mbps in Bluetooth 4.0 to 2Mbps for low energy applications. While it is not a massive increase, it will allow more data to be sent in a shorter time, consume less power, and have less risk of collisions in the air.

One of the biggest benefactors of this increase is probably IoT applications that require near-instantaneous communications, such as the control of surgical devices in medicine and machines in a production plant. They will also allow an IoT device to store data for days and send it together in seconds rather than periodically in parts. This will reduce power consumption on IoT devices, which is essential for extended battery life. Another benefit to IoT provided by the higher speed of Bluetooth 5, is the ability to allow sensors to update much faster and more frequently, which is critical to ensure that all devices on the network have the best security features. Recent and have the firmware updated.

In addition to the benefits that have been discussed, Bluetooth 5 has other enhancements that will increase its capabilities. Among them is its ability to coexist with other services in the 2.4GHz ISM. When developing Bluetooth 5, the SIG took into account that in many places, including those where IoT is used, Bluetooth will not be the only service in operation. To ensure minimal interference in these cases, Bluetooth 5 builds on existing capabilities, such as avoiding channels used by Wi-Fi, while adding “interval availability masks” that automatically detect and prevent interference with cellular networks. This will become increasingly important in the future as cellular networks expand to include frequencies very similar to those used by Bluetooth.

8. Conclusion

Bluetooth is the fastest growing wireless technology, due to its compatibility with most electronic devices; this makes Bluetooth outperform all other connectivity standards vying for supremacy in the world of IoT. Since all today's smartphones, tablets, and laptops incorporate Bluetooth, controlling IoT devices and networks is much easier and less expensive to implement. Combined with the new benefits incorporated in Bluetooth 5, it will allow the development of many applications in market sectors such as building automation, home appliances, medical devices, and personal electronics.

Bluetooth has always used a star topology in which each device must connect to a central hub. This severely limited its scope and scalability, and therefore its usefulness in IoT applications. A mesh network in Bluetooth 5 does not require a hub, which is a great advantage as this component adds costs and complicates network design. Mesh networking is the most useful feature of Bluetooth 5, allowing Bluetooth to cease to be a short-range technology for the first time in its entire history. However, its greater reach, improved support for Beacons, higher data rates, longer message length, improvements in power consumption, low cost of implementation, and massive market penetration, ensure that it will continue to be a highly competitive connectivity solution years to come. Beacons are one of the most successful use cases for Bluetooth, and with the features introduced by Bluetooth 5, Beacons are estimated to span the global market for IoT applications. Beacons can be used for a host of applications, and the mesh networking capability of Bluetooth 5 expands them more than ever. Any organization that wants to track people, packages, or anything can use Beacons to their advantage.

The ability of Bluetooth 5 to increase the range, allows a reduction in the number of access points and repeaters, which in the IoT domain represents an essential capacity to keep all the equipment and nodes in an IoT network connected. The extended range also means that Bluetooth 5 could replace Wi-Fi as a communication technology for many IoT applications. Besides, the higher speed allows to create, in a more natural way, communication channels with Beacons located in many different places; for example, public places: airport, train station, shopping center, or for home use.

Currently, it is difficult to predict what will be the wireless standard adopted in the IoT. All smart object connectivity is under development, however considering the significant improvements in speed, power consumption, range, and capacity, it appears that Bluetooth 5 is a strong candidate. Unfortunately, Bluetooth 5 does not allow updating old Bluetooth devices. The new version of Bluetooth requires a new type of chips that must be installed in newer devices. Older versions of Bluetooth may work fine on Bluetooth 5, but they do not have the same functionality. That is, they will continue to operate at their original speed and distance.

9. References

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