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Protocols for the Internet of Things

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Abstract: The Internet of Things (IoT) is a network of interconnected devices, and as this network grows, so does the need for an effective and safe protocol. Internet of Things (IoT) technologies are advancing quickly to meet the demand for the characteristics needed by applications, such as coverage area, scalability, transmission data rate, and applicability, referring to the designs of protocols. This is because of the vast range of uses and diversity of features required to meet an application. This article offers a thorough analysis of IoT protocols, including a comprehensive explanation of each protocol categorized by long- and short-distance coverage. For every set of protocols, a comparative analysis is carried out to offer insights into their traits, constraints, and behavior.

Keywords: IoT, Short Range Protocols, Long Range Protocols, LPWAN, LR-WPANs.

I. INTRODUCTION

Most (IoT) technology features are defined by the protocols used to design the technology for specific applications. Features such as network topology, power consumption, transmission power efficiency, and delays are important issues in the definition or choice of using a certain technology for a particular solution. [1]. Medium access techniques, data rates, communication mode between devices, transmission range, power consumption, and others are all examples of characteristics derived from the development and deployment of each protocol. Therefore, the study of protocols can show how to design a suitable technological solution for an application.

Based on its own needs, IoT applications may require the adaptation of the existing network protocols so that they can meet the requirements of IoT applications. Protocols may need to be adjusted, evolved, or developed to meet the IoT applications that demand different performance characteristics such as far-reaching, reliable, and robust low-power transmission techniques. The already existing definitions such as wireless Body Area Networks (WBAN), Wireless Personal Area Networks (WPAN), Low Rate Wireless Personal Area Networks (LR-WPAN), and wireless Local Area Networks (WLAN) can be classified as short-distance protocols due to their maximum range of 1 km.

While Wide Area Networks (WAN) and Low Power Wide Area Networks (LP-WAN) protocols can be used as references for long-range classification due to their ranges of more than 1 km. WAN protocols are commonly designed for user content and the media. Some of their evolution such as Long-Term Evolution (LTE) CAT-M have enhancements to support some IoT requirements such as lower power consumption. LP-WAN protocols came to attend long-range with low power consumption but enough data rate to attend IoT services requirements.

The purpose of this paper is to present a deep study of short and long-distance protocols used by IoT solutions, this study also gives inputs to obtain reference and comparison parameters in the design or choice of a technology to better serve a certain application, with specific characteristics. The rest of this paper is organized as follows. Section 2 elaborates on a detailed study of short-range coverage protocols. A deep study of long-range protocols is present in Section 3. Section 4 gives a summary of the lessons learned, and, finally, Section 5 concludes the study

II. SORT RANGE PROTOCOLS

Short-range coverage protocols are defined by the (IEEE) as Wireless Personal Area Networks (WPAN), which is the network established between elements that surround the human body. WPAN communication technologies differ from other conventional wireless network technologies. These networks call for easy connectivity to reach personal wearable or hand-held devices. Moreover, WPAN requires power efficiency, small size, low cost, and maybe most importantly easy-to-use devices [2,3].

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Short-distance technologies such as near-field communication (NFC) and radio frequency identification (RFID) are technologies that fit into this study context due to their usage with differentiated mechanisms for the physical and linking layers. Thus, their characteristics are less critical when compared to the IEEE 802.15.6 standard [4], which is dedicated to wireless body area networks (WBAN).

A. Radio Frequency Identification (RFID)

RFID refers to a set of technologies that are aimed at identifying and recognizing elements (tags). An RFID system is composed of two types of devices: the identified devices (tags) and the device identifiers or readers. Tagged devices are triggered by RF (Radio Frequency) waves emitted by the reader devices and reply its identification (ID) tags. Readers handle data exchange between them. When necessary, readers send RF pulses interrogating the tags in the area. Tags reply to this question by submitting their tag IDs. Different classifications of RFID systems can be provided according to operating frequency, radio interface, communication range, tag autonomy (completely passive, semi-passive, active), and different standards have been ratified. The evolution of smart UHF (Ultra High Frequencies) RFID tags with embedded sensors and miniaturization of readers promotes this technology for highly pervasive IoT ecosystems [5].
The various devices identified by radio frequencies (RFIDs) such as wristbands, clothing, footwear, and others are a combination of a small microchip and an antenna integrated into a single casing uniquely identified electronically. When readers send their interrogation radio frequency pulse, tags transmit their identification information to the reader devices using radio frequencies. This transmission takes place depending on the proximity of the tag to the reader device, even though it does not have a line of sight (LOS). The transmission range will depend on the class of device used. Transmissions occur from the low frequency (LF) bands at 124–135 KHz to the ultra-high frequency band (UHF). There are three classes of RFID devices [6] as follows:

PRAT—Passive Reader Active Tag.

ARPT—Active Reader Passive Tag.

ARAT—Active Reader Active Tag.

There is a certain variety of standards for RFID systems. ISO (International Organization for Standardization)/IEC (International Electrotechnical Commission) 14443 [7] are the entities responsible for defining the behavior and properties of smart cards. The standard defines the nomenclature of the 'reader device' as the Proximity Coupling Device (PCD) and the Tag Identified (TI) or, 'the object to be identified', is defined as the Proximity Integrated Circuit Card (PICC).

B. Near Field Communication (NFC)

For short-range communications, NFC technology is important since its massive adoption by mobile device vendors has popularized its use, making it accessible to the public for applications such as label reading or even peer-to-peer data exchange. The devices involved exchange information between themselves in a machine-to-machine connection mode [18]. Standardization of NFC is assisted by the International Organization for Standardization (ISO) conjoined with the International Electrotechnical Commission (IEC) and NFC Forum.

Near Field Communication is a short-range transmission technology that uses low-power transmission links that, differently from Bluetooth, do not require pairing for transmission. Just bringing one device close enough to the other allows communication.

C. Bluetooth IEEE 802.15.1

It is also called the Bluetooth Basic Rate (BR) and is a global 2.4 GHz specification working with short-range wireless networking. The IEEE 802.15.1 MAC layer is composed of Logical Link Control, the Adaptation Protocol (L2CAP) layer, the Link Manager Protocol (LMP) layer, and the Base-band or simply the Physical layer. The Bluetooth MAC layer handles the communication types that can be asynchronous connectionless (ACL) or synchronous connection-oriented communication (SCO).

D. Bluetooth Low Energy

Bluetooth Low Energy (BLE) is also known as Smart Bluetooth. BLE is an IEEE 802.15.1 variation with more suitable capacities for low-power applications than the classic Bluetooth Basic Rate. Devices that demand communication with both standards of Bluetooth are required to implement and support both protocols stacks due the incompatibilities among them. Star is the only topology accepted by BLE due to the standard definition that does not permit physical link connections among slave devices. Any data exchanged between two slave devices shall pass through the unique master and a slave device may not be connected to two master units at the same time.

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These premises define the formation of a BLE star pico-net [8]. A representation of the inter-layer communication structure and the relationship with Bluetooth layers of different Bluetooth versions can be seen in Figure 1.

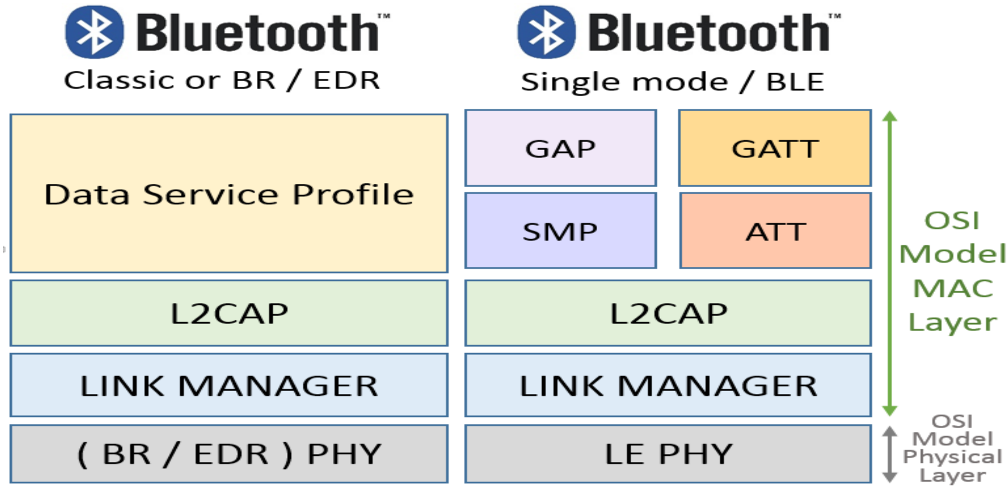

Fig. 1 Bluetooth power class classification.

E. *IEEE 802.15.4*

IEEE 802.15.4 is a subgroup of features that refers to physical and medium access control layers that can support ZigBee and 6LoWPAN upper. IEEE 802.15.4 focuses on physical and data link layer specifications while ZigBee Alliance aims to provide the upper characteristics [9]. It is a standard that defines PHY and MAC layers for personal area networks that demand low-rate and low-cost applications. This is also called a LR-WPAN protocol and has some advantages. Among them are a simple and flexible protocol stack, low cost, low energy consumption, short-range operation, reliable data transfer, and ease of operation [10]. These features are more important when operating in the Personal Operating Space (POS) also defined as a Personal Area Network (PAN) that involves the human body.

F. Wireless-HART

Wireless-HART (Highway Addressable Remote Transducer Protocol) is a variation of IEEE 802.15.4 design to work essentially as a centralized wireless network. IEEE 802.15.4 is designed to meet the requirements of industrial wireless applications with hard timing parameter restrictions, critically security issues, and severity on obstacle interferences. The Wireless-HART protocol has the same specifications as IEEE 802.15.4 PHY, but develops its own MAC layer based on the TDMA technique. Using Bluetooth, there is no guarantee to delay values on an end-to-end wireless communication. The absence of a hopping channel technique and a quasi-static star Bluetooth topology works against its scalability. These characteristics make them inappropriate to be used in industrial scenarios. Wireless HART comes as a solution for process control applications through the effort of some industrial organizations such as International Society of Automation 100 (ISA 100) [11], HART [12], Wireless Industrial Networking Alliance (WINA) [13] and ZigBee Alliance [14] to attend their specific requirements ratified by the HART Communication Foundation in 2007.

G. Z-Wave

Z-Wave was developed and is overseen by the company Zensys to provide wireless communication between devices with a focus on residential automation. Monitoring and controlling of lighting, ambient temperature, and security through sensors and actuators by tablets, smartphones or computers are some applications in its portfolio. Z-Wave devices are arranged in mesh network topology. They can send and receive messages from any device that is connected to the network [15,16].

H. Weightless

Weightless is the name of a set of LP-WAN protocols for wireless communication networks with low transmission rates. In this set, Weightless has the variations Weightless-P, Weightless-N, and Weightless-W. These technologies are standardized by the Weightless Special Interest Group (Weightless SIG) [17]. The Weightless network is a typical star topology system composed of the end devices (ED) and the base stations (BS). EDs are the sensor nodes or are also called leaf nodes and the base stations (BS) concentrate the communication with EDs. The interconnection with the base stations composes the base station networks (BSN) that, among other things, manage the system facilities such as authentication, roaming, and radio resource allocation and scheduling.

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I. IEEE 802.11 a/b/g/n/ah

Certainly, one of the most discussed and exploited standards in its functionalities and applications is IEEE 802.11. Its design has as an impulse the demand for high data transfer rates. Standardized by the IEEE as protocol for WLAN, its technology has evolved to meet the needs of increasingly specific demands. This evolution has initiated a group of IEEE 802.11 standards that have been merged, and named Wireless Fidelity (Wi-Fi). This group is the Wi-Fi Alliance [18] that certifies Wi-Fi products. In order to ensure that the Wi-Fi products meet the standards, this facility was named the WLAN System Toolbox which guarantees the compatibility of the market products in the PHY layer parameters.

In addition, it contributes to the exploitation of the various regional implementations, thus contributing to protocol evolution. The standard defines that communication devices are referred to as Stations (STAs) and can behave independently. Communication is directly between the two devices forming an ad hoc topology. The star topology happens when a certain STA is defined to be the traffic concentration point of other STAs, becoming an Access Point (AP). An STA-AP has a defined coverage area called the Basic Service Area (BSA) that allows it to associate with several STAs, forming a Basic Service Set (BSS). The STA-AP is usually connected to the internet or a WAN network through a wired connection. It is also possible to have a Distributed System (DS) connecting the various STA-APs of the same LAN by forming a transport backbone infrastructure called the Extended Service Set (ESS) [19].

III. LONG-RANGE PROTOCOLS

Based on their own requirements such as rate, distance coverage, robustness, etc., the existing network protocols need some adaptation to meet the necessary requirements to attend IoT services. In some cases, some protocols were developed to meet IoT applications that demand far-reaching, reliable and robust transmission. Some of the protocols classified as protocols for LP-WANs are able to satisfy the demand for protocols with a large coverage area.

LP-WANS protocols can overcome some mobile cellular network failures increasing strong adaptations to meet the IoT requirements. LP-WAN are presented as good candidates to support several of the previously mentioned requirements of the IoT structure and can surpass the short-range restriction of the LANs [11]. Among the possible solutions are the proprietary and unlicensed ISM band technologies Sigfox, LoRa/LoRaWAN, against mobile cellular network solutions such as LTE-A (Long Term Evolution—Advanced) and Narrow Band IoT (NB-IoT). Mobile cellular network technologies, with licensed spectrum or not, can satisfy energy and latency requirements, and it is better to use existing infrastructure [20-22].

Communication challenges and the broad set of specifications of M2M communication were added to LTE-based protocols. The development of MTC (Machine Type Communication) resources in the context of LTE (Long Term Evolution) was started in version 10, or Release 10 (R10), of the LTE-A standard. During the development of M2M communication, the 3rd Generation Partnership Project (3GPP) committee defined a new profile, called CAT-0, or Category 0, for the operation of the MTC of low-powerWAN (Wide Area Network) networks.

In release 13 (R13) from 2016, two special categories CAT-M for MTC and CAT-N for Narrowband-IoT (NB-IoT). These categories was included to support the characteristics of M2M communication and IoT technology, respectively. Such categories will be better addressed in the document. In the literature, it is possible to find references to the CAT-N standard as NB-IoT and the CAT-M standard as LTE eMTC, LTE-M2M, LTE-M and CAT-M1. In this document, the notation LTE eMTC and NB-IoT will be used.

A. NB-IoT

According to the LTE eMTC regional specifications, it can operate only within the bandwidth of an LTE carrier. NB-IoT systems can be implemented as autonomous systems in the Global System for Mobile Communications (GSM) band, employed in the LTE bandwidth carrier or the LTE bandwidth guard band. Due to the reduction of the NB-IoT bandwidth to 180 kHz, low data rate devices can have extended coverage, complexity reduction, and low power consumption. For scenarios with coverage problems of cellular network operators, NB-IoT is seen as the future of IoT devices using mobile network infrastructure .

B. LTE—Long Term Evolution

Long-Term Evolution Enhanced Machine-Type Communication (LTE eMTC) standards-based technologies support CAT-0 and CAT-M modes. While LPWAN LTE CAT-0 is commonly used to implement M2M/IoT, CAT-M reduces complexity keeping the coverage aspect using existing mobile cellular network infrastructure [23,24]. LTE eMTC counts on the same mobile technology benefits as security, privacy, data reliability, and device identification [25].

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C. LoRa—Long Range Protocol

LoRa defines a physical layer technology developed by Cycleo in 2010, a company that was acquired by Semtech from Camarillo, United States of America. The LoRa module manufacturer offers the user a programmed library that allows communication between LoRa nodes, providing a simple link protocol [26]. Libelium, a company based in Zaragoza, Spain provides the tools and libraries needed to operate with LoRa [27]. The LoRa protocol is an open standard defining physical layer to use direct sequence spread spectrum (DSSS) with multiple spreading factors that range from 7 to 12. This combination allows the establishment of a relationship between distance coverage and the desired data rate. This technique in the sub-GHz ISM band enables robust communication with a low power consumption for long distances. By using Frequency Shift Key (FSK) modulation with the optional use of forward error correction (FEC), LoRa allows demodulation of the signal even when the signal level is below the noise level. LoRa also counts on use of a frequency-modulated (FM) chirp, based on a spread spectrum modulation with a chirp spread spectrum (CSS) variation. Thus, LoRa modulates data in different channels and speeds them, with a forward integrated error correction (FEC). Thus, it is possible to increase the coverage range while maintaining the low energy consumption characteristics offered by the FSK modulation.

D. SigFox

SigFox is a technology that brings a new network and information strategy to IoT. Named by its developer, a group from Labège, France with the same name, SigFox is an IoT player with a network operator business model. Used by applications that require low data rates, SigFox is also classified as a Low Throughput Network (LTN) protocol, as defined by ETSI ERM TG28. Based on an Ultra Narrow Band (UNB) technology, Sigfox uses a 100 Hz transmission band in ETSI and ARIB (Japanese regulatory body Association of Radio Industries and Businesses) regions and a 600 Hz transmission band in FCC (Americas and Oceania) regions. This characteristic allows a data rate of 100 bps and 600 bps at ETSI and FCC regions, respectively [28, 29].

IV. LESSONS LEARNED

The diversity of application scenarios and network deployments directly or indirectly interfere with each protocol's performance. Protocol performance can be affected by uplink message factors, downlink message factors, throughput capability, delay tolerance, payload size, power consumption, or even the number of elements supported by the network [30]. Current and new applications come to explore and provide inputs for new studies and evaluations regarding transmission parameters, timing requirements, co-interference, and multi-use platform parameters. Concepts are being disrupted to follow the user needs evolution.

The coexistence of systems in the same frequency band deserves attention and detailed studies due to the explosive growth of technologies that will coexist in the same spectrum. A strong example is the coexistence of Sigfox, and LoRa protocols that already demand coexistence studies. Some adjustments, which are being made to adapt the current technologies with the new ones, at the same time that it attends the evolutional demand, are generating competition for resources.

M2M communication networks are being used on mobile devices as payment systems. In some cases, there is a sacrifice of energy to obtain a better result in another aspect such as latency, delivery time, or transmission data rates. There is little flexibility for protocols to adapt to these scenarios.

Often, the absence of control mechanisms can be justified regarding the energy aspect. Since these are new technologies in new scenarios for new applications, many parameters and capacities are informed by studies and theoretical comparisons [31]. Deployment and operation of these new technologies can present results far beyond those proposed by technology.

V. CONCLUSIONS

The study performed in this work explores the diverse characteristics of most of the protocols used that have been adapted, evolved, or created to meet the increasing needs and demands of new emerging IoT applications. The aspects addressed here are mainly related to physical and MAC layers bringing a comparative panorama to the range coverage, data rates, robustness, and energy efficiency aspects.

The lack of interoperability between protocols that challenges their heterogeneity in several aspects leads the paradigm of homogeneity to its separation. Characteristics of robustness, distance coverage, data transmission rates, and energy efficiency are aspects that contribute to protocol diversity allowing them to serve diverse applications.

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