LoRa – A Novel Protocol for Long Range Communication

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***Abstract*---Connectivity is probably the most basic building block of IoT networking. Up to now, there are many approaches used to establish connectivity with the Internet of Things such as GSM, Wi-Fi and Bluetooth. In such approaches, coverage area being small is a prime issue. Recently, these reference models have been challenged by a new type of wireless connectivity called LoRa which is characterized by low rate and long range transmission in the unlicensed sub-gigahertz frequency bands. In this article, we analyze the characteristics of LoRa environments having various numbers of user equipments, their efficiency, outage and throughput being compared.**

Keywords—IoT;connectivty;LoRa;longrange transmission;

I.INTRODUCTION

The Internet of Things (IoT) paradigm refers to a network of interconnected things, that is, devices such as sensors and/or actuators, equipped with a telecommunication interface, and processing and storage units. This communication paradigm should enable seamless integration of potentially any object with the Internet, thus allowing new forms of interactions between human beings and devices, or directly between devices according to what is commonly referred to as the machine-to-machine (M2M) communication.

The development of the IoT is an extremely challenging topic, and the debate on how to put it into practice is still open. The discussion involves all layers of the protocol stack, from physical transmission up to data representation and service composition [2]. However, the whole IoT system rests on the wireless technologies that are used to provide data access to the end devices.

For many years, multihop short-range transmission technologies, such as ZigBee and Bluetooth, have been considered a viable way to implement IoT services [3–5]. Although these standards are characterized by very low power consumption, which is a fundamental requirement for many IoT devices, their limited coverage is a major obstacle, especially when the application scenario involves services that require urban-wide coverage, as in typical smart city applications[5]. The experimentation of some initial smart city services has indeed revealed the limits of the multihop short-range paradigm for this type of IoT applications, stressing the need for an access technology able to allow a place-&-play type of connectivity, making it possible to connect any device to the IoT by simply placing it in the desired location and switching it on [6].

From this perspective, wireless cellular networks may play a fundamental role in the diffusion of IoT, since they are able to provide ubiquitous and transparent coverage [1, 7]. In particular, the Third Generation Partnership Project (3GPP), which is the standardization body for the most important cellular technologies, is attempting to revamp second generation/ Global System for Mobile Communications (2G/ GSM) to support IoT traffic, implementing the so-called cellular IoT (CIoT) architecture [8]. On the other side, the latest cellular network standards, such as Universal Mobile Telecommunications Service (UMTS) and Long Term Evolution (LTE), were not designed to supply machine-type services to a massive number of devices. In fact, unlike traditional broadband services, IoT communication is expected to generate, in most cases, sporadic transmission of short packets. At the same time, the potentially huge number of IoT devices asking for connectivity through a single base station (BS) would raise new issues related to signaling and control traffic, which may become the bottleneck of the system [6]. All these aspects make current cellular network technologies unsuitable to support the envisioned IoT scenarios, while, on the other hand, a number of research challenges still need to be addressed before the upcoming 5G cellular networks may natively support IoT services.

A promising alternative solution, standing between short-range multihop technologies operating in the unlicensed industrial, scientific, and medical (ISM) frequency bands, and long-range cellular-based solutions using licensed broadband cellular standards, is provided by so-called low-power wide area networks (LPWANs).

These kinds of networks exploit sub-gigahertz unlicensed frequency bands, and are characterized by long-range radio links and star topologies. The end devices are directly connected to a single collector node generally referred to as a gateway, which also provides the bridging to the IP world. The architecture of these networks is designed to supply wide area coverage and also ensure connectivity to nodes that are deployed in very harsh environments.

The goal of this article is to compare and analyze the efficiency of different LoRa environments having various end devices. We discuss the advantages provided by this new type of connectivity with respect to the more traditional solutions operating in the unlicensed spectrum, especially for applications related to smart cities. The section

II. LONG-RANGE IoT COMMUNICATION SYSTEMS IN UNLICENSED BANDS

Although the IoT paradigm does not set any constraint on the type of technology used to connect the end devices to the Internet, it is a fact that wireless communication is the only feasible solution for many IoT applications and services. As mentioned, the current practice considers either cellular-based or multihop short-range technologies. In the latter case, the connected things usually run dedicated protocol stacks, suitably designed to cope with the constraints of the end devices. Furthermore, at least one such device is required to be connected to the IP network, acting as a gateway for the other nodes. The architecture is hence distributed, with many "islands" (sub-nets) that may operate according to different connectivity protocols, and are connected to the IP network via gateways. The applications and services are deployed on top of this connectivity level, according to a distributed service layer. The applications may run either locally, that is, in the sub-net, or, more and more often (as typical in the smart city scenario), using cloud computing services. At this level we can find the IoT platforms that act as a unifying framework, enabling the service creation and delivery, as well as the operation, administration, and maintenance of the things and the gateways. Nowadays, the most important de facto standards in the IoT arena are the following: 1.Extremely short-range systems, such as near field communications (NFC)-enabled devices 2.Short-range passive and active radio frequency identification (RFID) systems 3. Systems based on the family of IEEE 802.15.4 standards like ZigBee, 6LoWPAN, and Thread-based systems 4.Bluetooth-based systems, including Bluetooth Low Energy (BLE); 5.Proprietary systems, including Z-Wave, CSRMesh (i.e., the Bluetooth mesh by Cambridge Silicon Radio, a company now owned by Qualcomm), and EnOcean 6. Systems mainly based on IEEE 802.11/Wi-Fi, such as those defined by the AllSeen Alliance1 specifications, which explicitly include the gateways, or the Open Connectivity Foundation.2 The AllSeen Alliance is dedicated to the widespread adoption of products, systems, and services that support the IoT with AllJoyn, a universal development framework [9]. The Open Connectivity Foundation has a similar aim, but different partners [10].

The vast majority of the connected things at the moment use IEEE 802.15.4-based systems, in particular ZigBee. The most prominent features of these networks are that they operate mainly in the 2.4 GHz and optionally in the 868/915 MHz unlicensed frequency bands, and that the network level connecting these nodes3 uses a mesh topology. The distances between nodes in these kinds of systems range from a few meters up to roughly 100 meters, depending on the surrounding environment (presence of walls, obstacles, etc.). To better appreciate the comparison with LPWAN technologies, it is worth highlighting the main characteristics of these IoT technologies.

As a counterpart of the unlicensed short-range technologies for the IoT mentioned in the previous section, we turn our attention to the emerging paradigm of LPWAN. Most LPWANs operate in the unlicensed ISM bands centered at 2.4 GHz, 868/915 MHz, 433 MHz, and 169 MHz, depending on the region of operation.4 The radio emitters operating in these frequency bands are commonly referred to as "short-range devices," a rather generic term that suggests the idea of coverage ranges of few meters, which was indeed the case for the previous ISM wireless systems. Nonetheless, ERC Recommendation 70-03 specifies that "The term Short Range Device (SRD) is intended to cover the radio transmitters which provide either uni-directional or bi-directional communication which have low capability of causing interference to other radio equipment." Therefore, there is no explicit mention of the actual coverage range of such technologies, but only of the interference caused. In this section we quickly overview three of the most prominent technologies for LPWANs: SIGFOX, Ingenu, and LoRa. In particular, we describe in greater detail the LoRa technology, which is gaining more and more momentum, and with specifications that are publicly available, thus making it possible to appreciate some of the technical choices that characterize LPWAN solutions. The medium access control layer is basically an ALOHA protocol controlled primarily by the LoRa net server.

SIGFOX

SIGFOX, the first LPWAN technology proposed in the IoT market, was founded in 2009 and has been growing very fast since then.12 The SIGFOX physical layer employs ultra narrowband (UNB) wireless modulation, while the network layer protocols are the "secret sauce" of the SIGFOX network and, as such, there is basically no publicly available documentation. Indeed, the SIGFOX business model is that of an operator for IoT services, which hence does not need to open the specifications of its inner modules. The first releases of the technology only supported unidirectional uplink communication, that is, from the device toward the aggregator; however, bidirectional communication is now supported. SIGFOX claims that each gateway can handle up to a million connected objects, with a coverage area of 30–50 km in rural areas and 3–10 km in urban areas. Regarding the security aspects of SIGFOX networks, very few comments can be made as the SIGFOX protocols are proprietary and therefore closed. However, as a general approach, SIGFOX focuses on the network security itself, leaving the payload security mechanisms to the end users at both the transmitting side, that is, the SIGFOX node, and the receiving side, that is, the applications linked to the SIGFOX cloud via application programming interfaces (APIs) or callback functions.

INGENU

An emerging star in the landscape of LPWANs is Ingenu from On-Ramp Wireless, a company headquartered in San

Diego, California. On-Ramp Wireless has been pioneering the 802.15.4k standard [12]. The company developed and owns the rights to the patented technology called Random Phase Multiple Access (RPMA) [13], which is deployed in different networks. Conversely to the other LPWAN solutions, this technology works in the 2.4 GHz band but, thanks to a robust physical layer design, can still operate over long-range wireless links and under the most challenging RF environments. From a security point of view, RPMA technology offers six state-of-the-art guarantees:

- Mutual authentication
- Message integrity and replay protection
- Message confidentiality
- Device anonymity
- Authentic firmware upgrades
- Secure multicasts

THE LoRa SYSTEM

The LoRa System LoRa is a new physical layer LPWAN solution, designed and patented by Semtech Corporation, which also manufactures the chipsets.14 LoRa PHY: The PHY is a derivative of chirp spread spectrum (CSS) [14], which has been innovated in order to ensure the phase continuity between different chirp symbols in the preamble part of the physical layer packet, thus enabling simpler and more accurate timing and frequency synchronization, without requiring expensive components to generate a stable local clock in the LoRa node.

The technology employs a spreading technique, according to which a symbol is encoded in a longer sequence of bits, thus reducing the signal-to-noise-plus-interference ratio required at the receiver for correct reception, without changing the frequency bandwidth of the wireless signal. The length of the spreading code is equal to 2SF, where SF is a tunable parameter, called spreading factor in the LoRa jargon, which can be varied from 7 up to 12, thus making it possible to provide variable data rates, giving the possibility to trade throughput for coverage range, link robustness, or energy consumption [15]. The system works mainly in the 902–928 MHz band in the United States and in the 863– 870 MHz band in Europe, but can also operate in the lower ISM bands at 433 MHz and 169 MHz According to the regulation in [16], the radio emitters are required to adopt duty cycled transmission (1 or 0.1 percent, depending on the sub-band), or the so-called listen-before-talk (LBT) adaptive frequency agility (AFA) technique, a sort of carrier sense mechanism used to prevent severe interference among devices operating in the same band. LoRa (as well as SIGFOX) uses the duty cycled transmission option only [17], which limits the rate at which the end device can actually generate messages. However, by supporting multiple channels, LoRa makes it possible for an end node to engage in longer data exchange procedures by changing carrier frequency while respecting the duty cycle limit in each channel. Furthermore, channels with carrier frequencies from 869.4 to 869.650 MHz fall in band g3.1 of Table 1 of the ERC Recommendation 70-03, for which a 10 percent duty cycled transmission and a much higher transmit power (27 dBm vs. the standard 14 dBm) are allowed. Therefore, this channel can be exploited for communications of longer messages over larger distances. The LoRa is basically an ALOHA protocol.

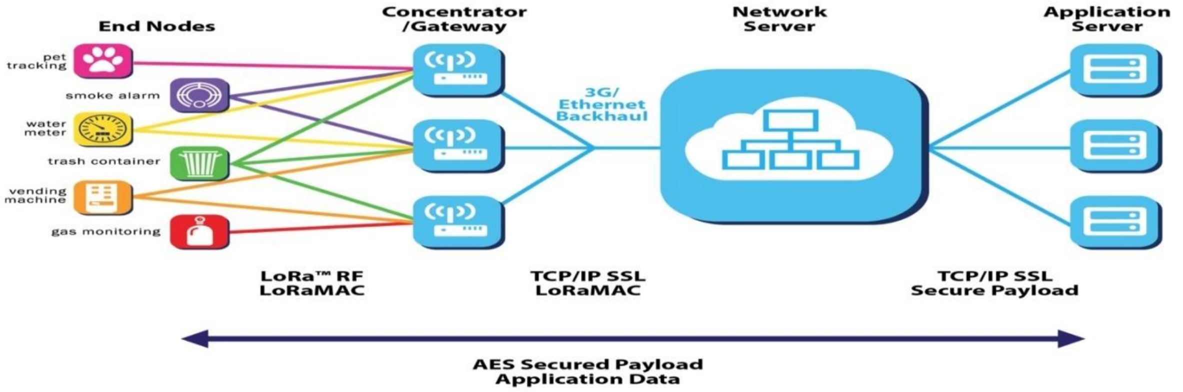

Fig1. LoRa architecture

LoRa IP Connectivity: LoRaWAN employs the IEEE 64-bit extended unique identifier (EUI) to automatically associate IPv6 addresses with LoRa nodes. Therefore, IPv6/6LoWPAN protocols can be deployed on LoRaWAN networks, thus enabling transparent interoperability with the IP-based world.

III. EXPERIMENTAL RESULTS

One of the most debated aspects of LPWAN is the actual coverage range. This is crucial for a correct estimation of the costs for citywide coverage, which clearly have an important impact on the capital expenditure of the service providers. In this article, we have created different LoRa environments containing variable end users. The numbers of users are being varied from 5 to 20 and the different experimental results are being analysed. Throughput, Outage, and efficiency of various environments is calculated and compared.

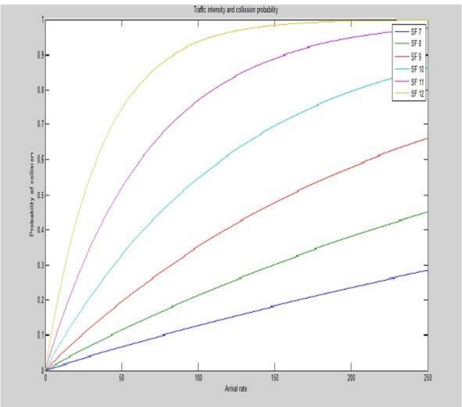

Figure 2. Comparison between arrival rate and probability of collision

It is found that as the probability of collision increases the arrival rate of the bits being sent from the net server is gradually decreased. The arrival rate of the LoRa environment is kept high by maintaining its traffic intensity.

PARAMETER	**UE=5**	**UE=10**	**UE=20**
Mean lag	142.707	143.682	233.749
Throughput	1.13e+3	1.16e+3	1.49e+3
Outage	0.7290	0.7043	0.6814

Table 1. Comparison of parameters in different LoRa environments

Throughput of the environment containing 20 user equipments is found greater than the environment containing 5 and 10 equipments whereas the outage decreases as the number of users increase.

IV.CONCLUSION

In this article we have described the new emerging LPWAN paradigm for IoT connectivity. This solution is based on long-range radio links, on the order of tens of kilometres, and a star network topology with peripheral nodes directly connected to a concentrator, which acts as the gateway to the Internet. Therefore, LPWANs are inherently different from usual IoT architectures, which are typically characterized by short-range links and mesh topology. The most prominent LPWAN technologies, SIGFOX, Ingenu, and LoRa, have been introduced and compared to the current short-range communication standards. The experimental trials performed employing LoRa technology have shown that the LPWAN paradigm has the potential to complement current IoT standards as an enabler of smart city applications, which can greatly benefit from long-range links.

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