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Emergent IoT Wireless Technologies beyond the year 2020 : A Comprehensive Comparative Analysis

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Abstract Low-power wide area networks (LPWANs) has recently emerged as a popular long-range and low-speed radio communication technology as a result of the important growth of the Internet of Things (IoT) market. In fact, LoRa, Sigfox and NB-IoT are the three major LPWAN technologies which compete for IoT deployment. In this manuscript, we analyze and compare these technologies. The latter are efficiently applied to intelligent, autonomous and heterogeneous devices. Within this framework, 5G networks have to be used to guarantee full connectivity in the IoTnetworks. To evaluate the IoT collection networks behavior, a set of experiments were conducted on real testbeds using wifi and zigbee technologies in an indoor environment.

Keywords: Internet of Things, Sensor, Wireless, 5G, LPWAN, LoRa, Sigfox, NB-IoT, BLE, EnOcean

I. Introduction

According to [1], by 2025, up to 75 billion devices would be connected to the IoT. The latter shows how data are connected and exchanged between devices or sensors. Nowadays, due to the exponential development of IoT technologies, there are a growing number of practical applications in various domains such as security, agriculture, smart cities and homes, etc [2].

Generally, IoT applications need particular requirements like: the low enough bitrate of the exchanged data, the reduced energy consumption, the important ranges, and the profitability aspect. In several cases, historically used short-range technologies such as Bluetooth and ZigBee cannot be adequately applied in scenarios requiring long-range transmission, especially for urban surveillance applications where the movement of connected objects is important. Solutions relying on cellular communications, such as 3G, 4G as well as 5G, ensure greater coverage. However, their power consumption from the device is very high [3], while causing additional connection costs imposed by the operators. Thus, a novel wireless communication technology appeared as a result of the need for IoT applications. This technology, considered as a serious candidate for IoT dedicated networks, is called Low Power Wide Area (LPWAN).

II. The arrival of LPWAN networks

LPWAN networks have recently become more popular in industrial and academic fields due to their low-power, long-range, and low-cost communication features. Long-range communication provided by A LPWAN network ranges, in rural zones, from 10 to 40 km, while it varies, in urban areas, between 1 and 5 km [4]. Besides, it is considerably energy-efficient. Battery life performance can attain more than 10 years [5] in some cases.Moreover, LPWAN networks are inexpensive in terms of hardware and subscription, especially for owners networks free of operator costs. These new LPWAN networks are finally perfectly suited to IoT applications in many cases. Nevertheless, their use is constrained by some limitations such as the fact that they can transmit only very small amounts of data for long-distance. This is due to their physical layer's instantaneous bitrates, which are also associated with penalizing cyclic reports. Among the currently most widely used LPWAN technologies: LoRa, LoRaWAN, Sigfox and NB-IoT.

III. Wireless technologies used for IoT

The newly-developed technologies used for IoT and their respective technical characteristics are represented in this part.

1. LoRa

In 2009, LoRa was initially introduced by the start-up Cycleo (in Grenoble, France). After three years, it was bought by Semtech (USA). Later, more specifically in 2015, its standardization was carried out by the LoRa-Alliance which used it in 42 countries. The deployment of this technology continued to spread in other countries because of the increasing investments of numerous mobile companies in France (Bouygues and Orange) and in Netherlands (KPN) as well as in South Africa (Fastnet), etc. [6].

LoRa is a physical layer technology used to transform signals into the sub-GHZ ISM band by employing proprietary spread spectrum method [7]. The CSS, broadcasting narrow-band signal over wide channel bandwidth, provides bidirectional communication. The produced signal is difficult to detect or block and has a low noise level giving high resilience to interferences [8].

LoRa utilizes six distinct spreading factors (SF) to achieve a compromise between the data rate and spatial interval. An increased spreading factor results in longer range at the cost of an inferior data rate and vice versa. The LoRa physical layer data rate ranges from 300 bps to 50 kbps according to the spreading factor and the bandwidth of the channel. Moreover, the largest payload size of each message is equal to 243 bytes. In 2015, the LoRa-Alliance standardized the LoRa radio layer-based network communication protocol named LoRaWAN in its first version. Using LoRaWAN, messages forwarded by a terminal are potentially received by various base stations in range. By examining such redundant reception, this technology enhances the quality of receiving message. Nevertheless, this characteristic necessitates multiple base stations in the neighborhood, which may raise the cost of employing network.

As demonstrated in Figure 1, a LoRaWAN network is based on a star network topology where a gateway faultlessly transmits messages between a network server (NS) and the End-Devices (EDs). The communication between the latter and the gateway (GW), on the one hand, and between GWs and the network server is done via LoRa radio layer and IP network (Ethernet, 3G, WiFi, etc.), respectively.

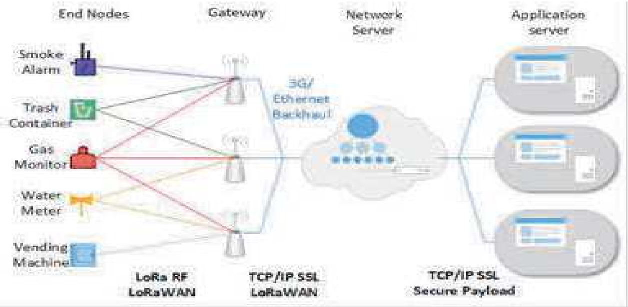

Fig. 1. LoRaWAN architecture [9]

2. SigFox

Start-up Sigfox (in Toulouse, France), a company and a LPWAN operator, introduced, in 2010, the Sigfox technology. It runs and sells its IoT solution in 31 countries [10].

Sigfox provides end-to-end IoT connectivity solution based on its own patented technologies. Its uses its proprietary base stations containing software characterized by cognitive radios (SDR) and links them to the major servers through IP network (3G, 4G, WiFi ...). Terminal equipment linked to these base stations employs binary phase-shift keying (BPSK) and a carrier within an ultra-narrow (100 Hz) ISM sub-band. However, Sigfox utilizes unlicensed ISM bands (e.g. 915 MHz, in North America, 868 MHz, in Europe, and 433 MHz in Asia.

Applying ULB (ultra-narrow band), Sigfox efficiently employs bandwidth and is characterized by its very low noise levels, causing reduced power consumption, increased receiver sensitivity and inferior antenna design cost, at the expense of the highest bit rate equal to 100 bits/s. Sigfox was first used to support uplink communication. Afterwards, it was extended to bi-directional technology by an asymmetric link which provides a low number of bits in the downstream path in order to link objects. Besides, downlink communication (data sent from base stations to terminal equipment) may take place merely after uplink communication.

Uplink messages, per day, are generally restricted to 140 messages with the largest payload length for each 12-byte message. However, on the downlink, this number is restricted to 4 messages per day. In fact, the largest payload length of each downlink message is equal to eight bytes. The factors behind the reliability of the uplink communication are the variety of time and frequencies together with the duplication of the transmission [3,10].

3. NB-IoT

The Narrow Band Internet of Things Network (NB-IoT), which was standardized by the 3rdGeneration Partnership Project (3GPP), represents a novel LPWAN technique relying on the technology of narrow-band radio. In June 2016, its conditions were issued in 3GPP version 13. Afterwards, in December 2016, NB-IoT was integrated into the Spanish Vodafone network by Vodafone and Huawei which forwarded subsequently the initial NB-IoT compliant message to a tool placed in a water meter. At present, the main focus of Huawei is to expend partnerships in order to apply this technology in many parts of the world (its first use was reported in a large number of countries in 2018). Then, in May 2017, the Ministry of Industry and Information Technology of China decided to increase the commercial employment of NB-IoT in public services [11].

The main objective of constructing the network was to satisfy particular market requirements resulting from the growing needs of IoT. This technology aims essentially at conveniently managing an increased number of linked tools and further extending the battery-powered nodes life by applying sleep algorithms. Using NB-IoT, mobile operators can provide novel network services according to a new user profile (UE) [12].

Figure.2 depicts the general architecture of the NB-IoT technology [13], [14].

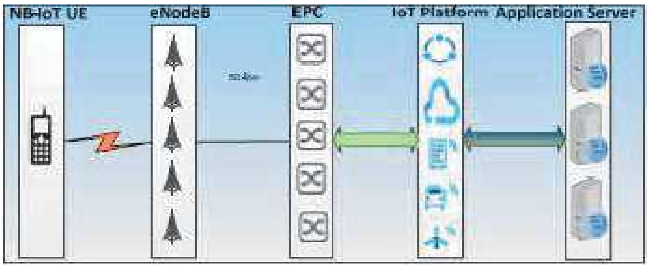

Fig. 1 NB-IoT Architecture [13]

Six distinct protocol layers form the NB-IoT architecture: the physical layer, the MAC (Medium Access Control layer), the RLC layer (Radio Link Control), the PDCP layer (Packet Data Convergence Protocol), and the RRC layer (Radio Resource Control) and the NAS layer (Non-Access). Indeed, LTE-based security support is given by the upper layers (primarily the NAS layer). However, security is provided by the PDCP and MAC and by several systems of access control and resource distribution [14]. As far as the RLC layer is concerned, it ensures both mobility and security, on par with LTE networks. The functionality provided by RRC layer of NB-IoT is the same as that given by the LTE.

4. BLE

Bluetooth represents a wireless communication protocol which aims at connecting mobile devices to each other. The energy consumption in BLE is an important requirement. Introduced for the first time in Bluetooth v4.0, the specification LE (Low Energy) offers wireless communications with reduced consumption and minimized cost [15]. The newly-developed Bluetooth standard v5.1 [16] retains similar Low Energy design as the Bluetooth v4.0 and v5.0 standard with an additional function called "Direction Finding" that determines the direction of the Bluetooth signal.

This version offers better location features, through the AoA arrival angle and the AoD departure angle, allowing you to know the direction, as well as the signal strength to get a more precise position.This v5.1 also includes an activity tracker associated with Bluetooth beacons that aims to reduce power consumption by 5 to 10 times compared to the standard level, to reduce it between 10 and 100 microwatts, with a rate of 1 Mb/s.

In order to maintain this consumption, another technology allows putting the device in a deep state of sleep.A very low consumption "earphone" material is charged allowing intercepting the radio transmissions, without emitting packets, in order to awaken the whole node.

In addition, v5.1 introduces the concept of "energy harvester", and allows the use of surrounding radio wave energy from 900 to 1400 MHz to generate a few microwatts and thus feed the chip itselfwhich is putinto a waking state on the rest of the time. This allows the chips to operate without battery.

Compared to its previous versions, Low-Energy (BLE) or Bluetooth Smart employs a short-range radio having more reduced amount energy in order to function for a longer period (even for years). Besides, its range, almost equal to 100 meters, is ten times longer than that of conventional Bluetooth [15]. BLE utilizes a transmission power ranging from 0.01 to 10 mW.

The above-mentioned characteristics make BLE efficiently applied in IoT applications [17]. Recently, smartphone manufacturers have developed hastily the BLE standard which becomes widely employed in most models and feasibly utilized in vehicle-to-vehicle communications and wireless sensor networks.

The BLE protocol stack can be described as follows: At the lowest level, bits are transmitted and received by a physical layer (PHY). Moreover, the link layer services including medium access, connection establishment, error control, and flow control. Afterwards, multiplexing of data channels, fragmentation and reassembly of larger packet are offered by the Logical Link Control and Adaptation Protocol (L2CAP). The remaining upper layers are: i) the Generic Attribute Protocol (GATT), offering effective data collection from sensors, as well as ii) the Generic Access Profile (GAP) ensuring the configuration and functioning in various modes like advertising, analysis together with establishment and connection management [15].

5. EnOcean

EnOcean represents a technology of an ultra-low power wireless communication powered by energy recovery. It is based on the combination of micro-energy converters and ultra-low power electronics to produce consistent wireless communications relying on a simple protocol stack [18].

The standard EnOcean specification consists of four layers: the physical layer, the data link layer, the network layer, and the application layer. The OSI layers 1 to 3 of the Wireless Short-Packet (WSP) protocol [19] were defined by the International Standard ISO/IEC 14543-3-10, while the application layer was standardized by the open and independent organization EnOcean Alliance [20]. The physical layer is responsible for adjusting data transfer on the 315 MHz frequency or the 868.3 MHz frequency band with a bit rate of 125 kbit/s employing the offset amplitude modulation (ASK) [19].

The system functional distance may attain horizontally 300 m. In data link layer, a direct access control (MAC) scheme is utilized by EnOcean. However, direct access to the media is employed by EnOcean to ensure the instantaneous transmission of a message by an IoT device. Afterwards, this device moves into standby mode [20], EnOcean can switch to forward their messages before exhausting the energy recovered by the switch pressing. Employing very compressed messages, a "Listen before Talk" mechanism as well as multiple message repetitions, Enocean can minimize the probability of message collisions and reduced energy consumption [21]. The roles of the network layer are as follows: extension of the EnOcean network with repeaters, management of collision avoidance and dealing with EnOcean telegrams.

6. 5G

IoT devices are used in some private places, such as homes, farms and factories, as well as in public areas like hospitals, streets, car parks.

Therefore, the connectivity profile is not the same as what we currently know in 4G cellular networks in which the most linked tools are smartphones which start novel data transfers according to the owner's profile.

Estimation about IoT devices indicated that the connection density will reach, by 2020, 106 devices/km2 [5]. Therefore, radio access technology must address a high number of heterogeneous devices and a large volume of data used by smartphones. In fact, the 4G network cannot support the envisaged IoT services despite the fact that many attempts aimed at developing this type of service with a short-term evolution (LTE) in the latest 4G versions [6]. Maintaining orthogonality and synchronization among users and radio base stations (RBS), for instance, necessitates a huge amount of energy. Thus, battery-powered devices are not able to function during long periods without replacing the battery. This problem is one of the most important weaknesses of IoT scenarios [22].

	LoRa	NB-IoT	SigFox	BLE	EnOcean
Modulation	CSS	QPSK	BPSK	GFSK	ASK
Frequency	Unlicensed ISM bands	Licensed LTE frequency bands	Unlicensed ISM bands	ISM	ISM
Bandwidth	125 KHz/ 250KHz	200 khz	100 Hz	2 Mhz	280KHz
Data rate (Maximum)	50 kbps	200 kbps	100 bps	500 kbps (coded) 2 Mbps (uncoded)	120kb/s
Energy consuption	Low	Low	Low	Very low autonomy	Very low autonomy

Table 1. Comparative table between wireless technologies used for IoT

V. Results of real experiments

To evaluate the IoT collection networks behavior, we suggest utilizing an IoT testbed network and examine some deployment approaches (two optimization algorithms: NSGA-III and MOEA/DD; and two deployment geometric approaches: 3D Virtual Forces and 3D Potential Field). The used simulation model takes into account a routing layer relying on a reactive AODV protocol, a non-coordinated IEEE 802.15.4 CSMA/CA access method, and a physical layer of 433 MHz.

The employed TeensyWiNo nodes technical features are as follows: the CPU is an ARM Cortex M4 (32bit) 72MHz; the RAM is 64 kB ; the Flash is 256kB (PJRC Teensy 3.1 and the Arduino Transceiver is based on a HopeRF RFM22b with 200-900 MHz, 1-125kbps.

The experimental parameters are as follows: Unless indicated, there are 29 fixed nodes, 6 nomad nodes and one mobile node. The mobile node sends the first message to trigger the simulation process. The bit rate is 256 kbps. The RSSI is 100 and the FER is 0.01. The initial indoor transmission (sensing, to respectively) range is 7m (8, respectively). The modulation model is 125 kbit/s GFSK and the frequency is 434.78 Mhz. The average of runs of experiments is 25.

*** Coverage rate vs time**:Fig.2 illustrates the coverage rate according to the time. It shows that for low execution time, the 3DVP is more efficient; whereas the optimization algorithms (NSGA-III and MOEA/DD) are more efficient for higher number of iterations.

*** Coverage rate vs number of iterations/rounds**: Fig.3 shows the change of coverage rate in terms of the number of iterations (rounds, respectively) of NSGA-III and MOEA/DD (VF and VP, respectively). Fig. 3 shows the evaluation on the optimization techniques in terms of the convergence rate.

*** Coverage rate vs number of nodes**: For a RoI of 700x700x700, 100 iterations and a radius of 20, Fig.4 represents the coverage rate in terms of the number of nodes. It shows a stable behavior of the algorithms according to the number of nodes: MOEA/DD is the best, 3DVF and 3DVP are the worst.

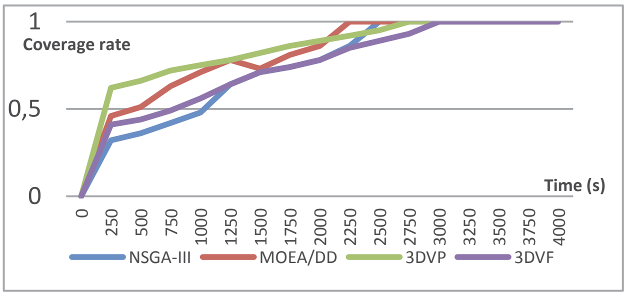

Fig.2 The coverage rate according to the time

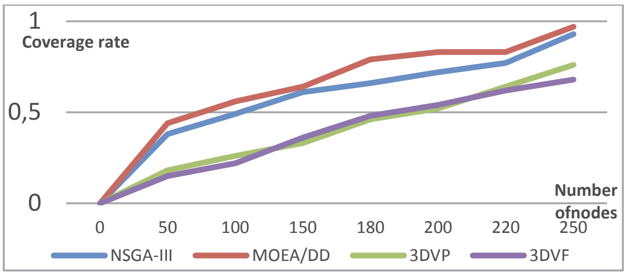

Fig.4 The coverage rate according to the number of nodes

V. Conclusion

This paper summarizes the technical differences between Sigfox, LoRa, NB-IoT, IEEE.802.4, UWB, BLE and 5G and discusses their advantages and major problems in terms ofIoT factors. Each technology have its place in the IoT market. Sigfox and LoRaare the least expensive solutions, especially with a very long range, a low communication rate and a long battery life.

In this manuscript, we show the technical discrepancies between Sigfox, LoRa, NB-IoT, IEEE.802.4, UWB, BLE and 5G. We also discuss their main strengths and limitations in terms ofIoT factorsIt is obvious that Sigfox and LoRa constitute the least expensive technologies, particularly with a very long range, a reduced communication rate and an extended battery life.

Besides, the behavior of IoT collection networks was acessed in an idoor environment by a set of tests using a real protoyping experiments.

To sum up, unlike Sigfox, LoRa is an open source network that can be developed and operated by any company. Each LoRa operator can have its own network and therefore its own coverage map. On the other hand, NB-IoT will be present in higher value-added IoT markets, for customers who are ready to pay for considerably reduced latency and services of high quality.

***Coverage rate vs sensing radius**:For a RoI of 700x700x700, 100 iterations and a number of iterations of 500, Fig.5 illustrates the coverage rate according to the sensing radius. It shows that for very low and very high sensing radius, the optimization algorithms are better than other approaches, while 3DVF is more efficient better than NSGA-III for medium sensing radius values.

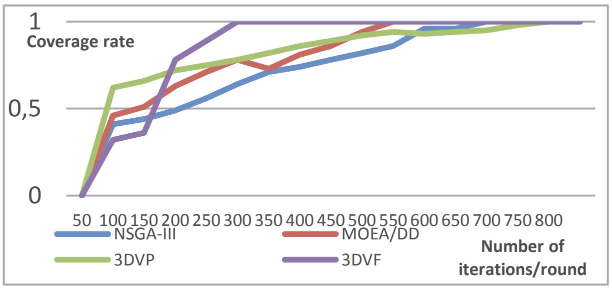

Fig.3 The coverage rate according to the number of iterations/rounds

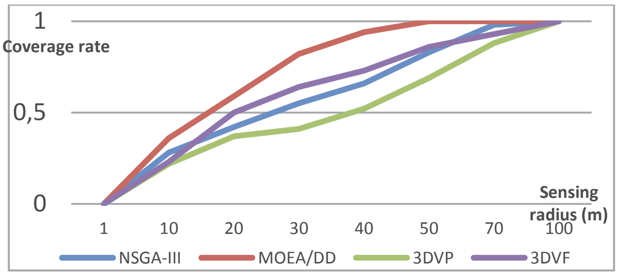

Fig.5 The coverage rate according to the sensing radius

The unique beneficial feature of EnOcean and Bluetooth 5.1 devices is their ability to run without batteries and to communicate wirelessly to the point of ending up with self-powered devices that run out of battery. Ultimately, we may deduce that, the use of the 5th generation (5G) will allow, by 2020, the wireless mobile to form a fully-connected world of humans and devices, creating a global LPWAN solution for IoT applications.

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