A Comparative Study on Emerging Radio Technologies for IoT

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***Abstract*— A recent study says by 2020, about 50bilion device needs to be connected in this universe. Of these 50 billion devices, most of the invention would be an IoT device that sleeps most of the time and transmits or receive data occasionally. These devices are battery powered in most cases. Existing wireless technologies usually consume lots of power, hence cannot be applied for their low powered IoT devices. For these reasons, different types of Low Power (LP) technologies have been proposed in recent days to work with low-power devices. The most appropriate strategies for IoT implementations are IEEE 802.11ah, LoRaWAN, SigFox and these Low Power Large Area (LPWA) technologies supplemented by current traditional cellular and other approaches for the numerous developing machine-to-machine communication, smart home and smart city implementations. In this paper, different types of such LPWA technologies standards, limitations, regulations, stakeholders' interests have been being considered. This paper gives several LPWA frameworks an idealistic vision and provides a study of such innovations to illustrate the integration of billions of devices over the next decade.**

Keywords—802.11ah, LoRa, LoRaWAN, CSS, SigFox, Ingenue.

I. Introduction

The WSN technology has extensively emerged for the different probable fields of our living, such as security, transportation, and infrastructure management. In most instances, these sensor nodes linked to the Internet are known as the Internet of Things (IoT) network. It can help us to mitigate many global challenges such as environmental pollution, increasing food productivity, waste management, proper metering technology, and energy crisis. This large number of IoT are densely installed over a large arena and connected. They collect physical or environmental data as per the sensor connected with and send them to a sink node for further processing and making available to effortless access by the user. To complement existing cell-based and other short-range radio technologies, LPWA is a novel approach to facilitate radio connection in a massive end node network. This technique facilities are working with power constraint end devices, whereas this sort of service does not support traditional technologies. The study says about 25% of IoT/M2M devices can be connected through LPWA that are currently using conventional or cellular techniques [1]. The main facilities offered by LPWA is to provide connectivity over the large geographical area with variable data rates as per the requirements by the network. For instance, in the case of M2M communication, 802.11ah can be a useful technology for short-range and remote connection with low power up to 1-kilometer can be covered with a maximal 150kbps data rate.

Further, as the coverage area is big, these end devices can move inside this area if it needs, as an example, Unmanned Aerial Vehicle (UAV) objects or mobile wireless sensor networks. Standard short-range radio systems such as ZigBee, Bluetooth and Wi-Fi are not capable of providing such facilities. This versatility can be accomplished by conventional cellular technology, but this strategy does not help low-powered devices, because such methods also require a lot of speech and message control, and this trend exhausts low-powered IoT devices. Besides, the complexity of the IoT device is simple, and it cannot process the complex formulated cellular data. While supporting coverage distance up to 50 kilometers (maximum) and on an average 10-15 kilometers [2] and end device with survival capacity with the first installed battery, LPWA technologies are offering Internet of low-energy, minimum-cost, and as per throughput required for these devices. With these technologies anywhere, IoT or M2M devices can be connected at any time either to sense the environment or to make comfortable human life. LPWA gives long-distance coverage for energy constraint device, but it is true that these are achieved at the cost of latency and decreased data rate. Therefore, in the end-devices where these two parameters are essential and need to maintain a particular threshold level strictly, these LPWA cannot be used. In conjunction with application areas such as Massive Machine Type Communication (mMTC) [3] that requires very low latency and tremendous-high reliability, LPWA technologies cannot be used. The same explanation is applicable for application areas such as Vehicular communication or Critical MTC [3]. Such low latency and high reliability cannot be accomplished at the lowest cost possible. Most competing LPWA technologies are available at current or evolving phases of low power operating and fast scalability of long-range support.

Continued sections of the paper are structured as follows: Section II describes the desired properties of IoT radio technologies. Section III discusses several well-known IoT radio technologies, their features and a comparative study about their different parameters. Section IV includes some reviews about detailed investigations, Section V contains a conclusion, and the last Section ends with references.

II. IoT Radio Properties

The desired LPWA technologies should have a low-powered running ability to be compatible with massive number IoT/WSN nodes over large geographical networks. In recent years, different working body and business consortiums have proposed several such technologies. Some of them are based on a brand new concept, whereas some of them depend on existing technologies. Most methods include legal frequency bands, some of which operate in the unregistered sub-1 GHz range and are thus safe but experience interference due to the vast number of instruments that can use this range shortly or have already been used. Now, we would like to explain some of the most expected service characteristics from IoT and WSN connecting technologies. It is expected that the most favorable technology would support different variety, such as the antenna, hardware, and channels. (1) Minimum infrastructure: To develop any infrastructure is expensive, also needs money to implement, and it would need more control and maintenance of more support. Hence, for IoT applications, it is demanded to deploy as much as simple infrastructure to be implemented in a short time. (2) Narrow-band: Conventionally, IoT technologies would use simpler narrow waveform as narrow-band consumes less power. (3) Support heterogeneous network: It is hoped that IoT technologies would support backward compatibility and various technologies supporting properties. Because of possessing such properties existing old technologies and a wide range of similar techniques can be compatible. (4) Duty cycle (gateway and endnote): In the future, the total number of IoT devices would be higher. Consequently, the gateway device should have a high capacity to support lots of IoT devices. For this reason, the gateway should have a high percentage of duty cycle to support these high number of end devices. (5) Friendly for simple end node device: The RF technology of IoT server node should be approachable with the end device that means it should be compatible with power constraint end devices regarding controlling and further signal processing. (6) Low power: IoT devices are mostly running on battery power, and hence they are power constraint devices. It follows that the radio technology should also be power constraint. (7) Long-range: In an idealistic case, as much as the distance of the radio technology capable of covering is better because of for this case, it would need a fewer number of the gateway (if not more gateway requires due to gateways duty cycle limitations). (8) Adaptive data rate: There are many known and unknown environment reasons for which the radio signals cannot support the stipulated data rate. For this situation, IoT radio technology should have adaptive data rate selection depending on environment changes or for some other reasons. (9) Short header: It requires the header section of an IoT data packet would be shorter as it needs the power to deliver the packet to the gateway. The header section carries the redundancy of data, and a short header is a right candidate for IoT applications. (10) Forward Error Coding: The forward error coding (FEC) should also be short because, for error correction purposes, less redundancy bit is carried out. (11) Interference prune technology: Radio technology always suffers problems from environmental obstacles and hence fading, multipath fading, delay in propagation, and phase shift problem arises. To solve these radio propagation challenges on signals, it needs different advanced coding techniques, and for this reason, the circuitry of the end device would be complicated. For these reasons, it is habitual that IoT radio technology needs to be interference prune. (12) Topology: There are various forms of network topology, such as mesh, tree, or star topology. Of the topologies, the topology type of star is easy to implement, relatively inexpensive and more stable than all other topologies. Star topology is generated by connecting all the network devices to the central computer. The central connection allows the network to restart service even though the cable or single node fails. The most important downside of the star topology is that if a central node (called a gateway) fails, the network will become unreliable or will cease to function [4].

III. Well-Known Technologies for IoT

A short overview of IEEE802.11ah, LoRa, SigFox and Ingenue will be addressed in this section.

A. IEEE 802.11ah

The standard MAC and PHY layer of the IEEE 802.11, which operates in a non-licensed sub-1 GHz band, is an energy limiting wireless radio communication technique. For example, in Asia, 917.5 to 923.5 MHz (China), 916.5 to 927.5 MHz (Japan), and 902–928 MHz (North-America), this Sub-1 GHz frequency range ranges globally due to national and policy legislation. It is made by downgrading the 802.11ac by ten times lower. Its coverage area is up to 1km while maintaining a data rate of 150kbps and for a shorter distance up to 78Mbps that may be suitable radio technology for massive IoT, M2M applications [5]. It has a restricted access window (RAW) feature by which it can scale a considerable number of end-device per gateway. RAW allows portal gates to separate end-users into classes, limiting the connection to a single group of concurrent channels and eliminating collision. For the MAC layer, the hierarchical association identifier (HAID) with a virtual map regulates large numbers of devices per gates.

B. LoRa

LoRa is a technology of the physical layer that Semtech Corporation created and marketed [6]. It operates on a range of frequencies sub-1 GHz using the CSS [7] technique. Through this technique, CSS signals are distributed over a wider range of channels. It is a bi-directional communication system that allows the end devices to enter the gateway and vise - versa. The LoRa is somewhat a frequency modulation that is inherently pruned to fading and other environmental effects. As it is the frequency modulation technique, its frequency is varied over time, not the phase. The frequency spreading is an essential parameter of the LoRa system, and its standard value is from 7 to 12. LoRa gives the network a substantial connection budget, a sufficient gain that allows it to transmit signal forces and lower the noise floor while at the same time rendering it resistant and Doppler shift, multipath flickering, and narrow-band interference [8]. LoRa's energy usage and coverage performance are focused on the spread parameter, bandwidth and coding rate. The spreading factor's larger values disperse the signal out over time, consuming extra energy per transmitted bit, resulting in a better transmission over longer wavelengths. Nonetheless, this also raises on-air time (OTA) and decreases the effective data rate. It is critical that the independent spreading factors are orthogonal and do not intervene with the LoRa system. Broader channel BW achieves higher data speeds but is met with more noise, which acts as a deterrent to extending the spectrum. Therefore, LoRa uses FEC for efficiency and range enhancement. The CR specifies the reliability of data transmitted and raises the on-air time marginally [8]. As a general protocol interface, LoRaAlliance introduced LoRaWAN at the top level of the LoRa device. This flexible protocol specifies the mechanism by which the terminals are connected to one or more LoRa gateway (GW) with the unlicensed radio frequency on the GHz sub1 bands. The GWs are linked through the downstream to a network or servers. According to international policy, the regulatory organization allocates different ISM bands across multiple regions of the world. For this reason, LoRa Alliance makes distinct recommendations of using frequencies for Asia, Europe, North America, or Australia. LoRaWAN transmits a signal using the multifunctional access system (MAS) derived from

TABLE I. COMPARATIVE PARAMETERS OF 802.11AH, LORAWAN, SIGFOX, AND INGENUE

	802.11ah	LoRaWAN	SigFox	Ingenue
Modulation	BPSK~QPSK/16-QAM~256-QAM	CSS	UNB DBPSK(U), GFSK(D)	RPMA-DSSS(U), CDMA(D)
MAC Power	×	√ (A, B and C)	×	×
Band (Hz)	Sub 1GHz Typically 769~935M	EU: 433~ 868M, US: 915M, Asia: 430M Hz	EU:868M, US:902M	ISM 2.4G
Num. of Channels/Orthogonal Signals	?[a]	10 ([EU], 64+8(UL); 8(DL) [US] + several SFS	360 channels	Channel: 401 MHz
Link Symmetry	√ [b]	√	×[c]	×
FEC	√	√	×	√
MAC	CSMA/CA [9]; RAW [10]	unslotted ALOHA	unslotted ALOHA	CDMA-like
Payload	475Bytes (LH), 485Bytes (SH) [10]	up to 250B	12B(UL), 8B(DL)	10KB
Handover	?	connected to multiple base station	connected to multiple base station	√
Authentication	WPA in the MAC layer (AES) [11]	AES 128b	encryption not supported	10B hash, AES 256b
Propagation model dev.?	√	?	?	?
WAN Simulator	developed; not public released	developed; not public released	?	?
BW	1, 2, 4, 8, 16 MHz [12]	125kHz	Narrow 100kHz	1000kHz
Antenna	MIMO	?	?	?
Topology	Star [13]	Star of stars	star	Star, tree
Comments	3GPP	LoRaWAN: open standard	Software managed	On-Ramp wireless

[a]un-known; [b] supports; [c] does not support, D=Download, U=Upload

a basic ALOHA device, which uses no carrier sensing or listens before talk (LBT) mechanism. Besides, there are other limits on the use of the duty cycle in the ISM band (868 MHz and 433 MHz) for LoRaWAN in Europe, which is 1% normal by example. Besides, while most sub-bands restrict bandwidth to 14 dBm, the transmitting capacity for LoRaWAN is restricted to 20 dB (maximum). Such constraints prompted LoRaWAN to propose a few different values for SF, BW and CR (SF 7-12), BW[125, 250, 500 (kHz)]. This SF, BW and CR values can be modified using the Adaptive Data Rate algorithm during run-time by controlling the accuracy of up-link data and by modifying these parameters on the remote end system to enhance stability and power usage. LoRaWAN describes three types of tools, based on the requirement for network traffic. By default, the class is class A, where it can receive downlink data just after uplink events. Class B system sleeps most of the time and wakes up regularly to collect periodic pre-scheduled results. However, the class C device always listens to the servers; thus, it is more power-consuming. LoRaWAN offers different system rates and network-level security mechanisms that rely on symmetrical encryption techniques to encrypt information.

C. SigFox

With the help of SigFox technology, billions of devices data can listen without the necessity of establishing new infrastructure as well as maintenance costs. SigFox is the first of its kind considering of its virtual working mechanism. The operating principle of SigFox is unique because it needs no overhead signaling, very lightweight, simplified protocols, cellular networking to terminal devices, and terminal devices are not directly attached to backbone networks. So, how it works? SigFox is a cloud-based end device managing platform where most tasks are managed by software which does not work on the end device. With all of these facilities, it significantly reduces energy utilization and the costs of connected devices [14]. SigFox utilizes vendor-specific cell towers over the traditional IP-based network fitted via software-based communications connected to the servers. Through BPSK transmission, the end devices link with the 100Hz Sub-1 GHz frequency to these cell sites. The links of SigFox is asymmetric means both download, and uplink does not possess the same property. The DL can only operate until the UL transfer has completed, and except for that, the end-user will have to listen and wait for the update from the base station.

Further, the UL and DL modulation is different; UL uses BPSK while DL uses the GFSK modulation technique. Every message may not be acknowledged as the frequency is unlicensed ISM band to convey the regional regulation, the number of message transfers at the rate of 140 12-byte messages per day [15]. It supports minimal mobility up to 6 kilometers per hour. The data transmission between the end node and the base station become successful even if there happens collision with other objects or interference from different frequency bands successfully [15]. The sub-band service cycle limits used for the European ISM band of 868 MHz are 1%. According to SigFox technology, each terminal system will transmit just 36 seconds every hour. On-air time is 6 sec [16] per packet, and so the average time for six messages an hour is 4, 8, or 12 bytes [15]. As mentioned before (every message may not be acknowledged), this means it lacks adequate acknowledge facility, but still, it is enough reliable with only three times reliability is being achieved? The reliability can be improved through the redundant transmission of packets through multiple times over different channels.

D. Ingenu

Compared to other mentioned technology, it possesses LPWA properties, but it works in 2.4GHz. Being operated with this frequency band, Ingenu achieves benefit more flexible frequency regulations across different regions [17], [18]. As an example, on Sub-1GHz frequency has the regional duty cycle and total message transmission over a day and message size are limited in size. However, on 2.4GHz, there are not such strict duty cycle limitation, so it offers comparatively higher throughput. Ingenu uses a channel accessing scheme called random phase multiple access (RPMA) [19] a variation of code division multiple access (CDMA) technique. The difference is it first increases the time slot in a usual manner and later spreads over the channel by introducing an arbitrary offset delay for each end device. Table I presents a comparative study about the IEEE 802.11ah, LoRaWAN, SigFox and Ingenue radio communication standards.

IV. Performance Study

Research has been carried out regarding fixing further issues about these technologies to verify the specifications and implementing in testbed or optimizing different parameters. As an example, [19] has tried to confirm to 802.11ah path loss model through implementing a prototype system, and they agreed that their testbed result and specified path loss model are well fitted. However, in another study, they have disagreed that the acceptable throughput at a distance of 1 kilometer is not 150kbps for the IEEE 802.11ah model. In [8], the authors are interested to see the massive number of node's effects connected with a gateway. They discussed how LoRaWAN functions like two-way communication, and the function limits would gain from their developed LoRaWAN ssimulator. It also delivered new ideas, including network scalability, stability and energy usage trade-offs.

TABLE II. Characteristics

	802.11ah	**LoRaWAN**	**SigFox**	**Ingenue**
Range	<1.5 km	5 km, 15km	10km, 50km	15 km
Adaptive Data Rate	√ (MCS)	√	×[c]	√
Over the air updates	?[a]	√	×	√
Localization	√[b]	√	×	×
Nodes per gateway	6000[20]	$\approx 10^4$ [21]	$\approx 10^6$[21]	$\approx 10^4$[21]
Data Rate (bps)	150k-346M	0.3 to 37.5 k, 50k FSK	100 (U), 600 (D)	78k(U), 19.5k(D)

[a]un-known; [b] supports; [c] do not support; U=Upload, DL=download

The authors [8] also showed that the downlink traffic would quickly overflow Lo RAWAN gates with a limited duty cycle time. They have also demonstrated that these networks are not very robust as other terminals call for acknowledgment. Table II presents range, data rate, localization supporting advantages, number of nodes supports by single gateway for the LPWA technologies.

V. Conclusion

In this assessment, we have provided a brief description of famous and well-known radio propagation technologies, as the next candidate for massive IoT and M2M applications. Refer to the comparative table, though there are several studies and research for standardization about Physical and Medium Access Layer in recent days, the upper layer functionalities are mostly still being un-accessed. Research work can be carried on this technology to develop top layer functionalities, security, and adaptability in a heterogeneous network. As an example, according to the LoRa technology, there is no coordination exists in LoRa among A, B, and C classes of devices. Is it possible to make it intelligent enough to be adaptive based considering power and transmission requirements? Similar type many insightful research areas, many research scholars are working for the betterment of IoT radio technology.

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