Low Power Wide Area Networks: An Overview

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***Abstract*—Low power wide area (LPWA) networks offer affordable connectivity to the low-power devices distributed over very large geographical areas. LPWA technologies complement and sometimes supersede the conventional cellular and short range wireless technologies. LPWA technologies exploit to offer wide-area coverage to low-power devices at the expense of low data rates. Researchers survey several emerging LPWA technologies (e.g., LoRa, Sigfox) and the standardization activities carried out by different standards development organizations.**

***Index Terms*—Internet of Things, IoT, low power wide area, LPWA, LPWAN.**

I. Introduction

THE Internet of Things help us in overcoming the top global challenges resulting from population explosion, energy crisis and resource depletion. Number of connected M2M devices and consumer electronics will surpass the number of human subscribers using mobile phones, personal computers, laptops and tablets by 2020 [2]. By 2024, the overall IoT industry is expected to generate a revenue of 4.3 trillion dollars [3]

LPWA technologies offer unique sets of features including wide-area connectivity for low power and low data rate devices, not provided by legacy wireless technologies. LPWA networks are unique because they make different tradeoffs than the traditional technologies prevalent in IoT landscape such as short-range wireless networks. The legacy non-cellular wireless technologies are not ideal to connect low power devices distributed over large geographical areas. The range of these technologies is limited to a few hundred meters at best. The range of these technologies is extended using a dense deployment of devices.

With a phenomenal range of a few to tens of kilometers [4] and battery life of ten years and beyond, LPWA technologies are promising for the Internet of low-power, low-cost, and low throughput things. It is worth clarifying that LPWA technologies achieve long range and low power operation at the expense of low data rate and higher latency. Therefore, it is clear that LPWA technologies are not meant to address each and every IoT use case. Specifically, LPWA technologies are considered for those use cases that are delay tolerant, do not need high data rates, and typically require low power consumption and low cost.

At this moment, there are several competing LPWA technologies, each employing various techniques to achieve long range, low power operation, and high scalability.

II. DESIGN GOALS AND TECHNIQUES

LPWA technologies share some of the design goals with other wireless technologies. The key objective of LPWA technologies is, however, to achieve a long range with low power consumption.

A. *Long Range*

Quantitatively, a +20 dB gain over legacy cellular systems is targeted. This allows the end-devices to connect to the base stations at a distance ranging from a few to tens of kilometers

1) *Sub-1GH Band*

Most of the LPWA technologies use Sub-GHz band, which offers robust and reliable communication at low power budgets. Lower frequency signals experience less attenuation and multipath fading

2) *Modulation*

The physical layer compromises on high data rate and slows downs the modulation rate to put more energy in each transmitted symbol. Two classes of modulation techniques namely narrowband and spread spectrum techniques have been adopted by different LPWA technologies. Narrowband modulation techniques provide a high link budget by encoding the signal in low bandwidth. Spread spectrum techniques spread a narrowband signal over a wider frequency band but with the same power density.

B. *Low Power*

A battery lifetime of 10 years or more with AA or coin cell batteries is desirable to bring the maintenance cost down.

1) *Topology*

Mesh topology has been extensively used to extend the coverage of short range wireless networks, their high deployment cost is a major disadvantage. LPWA technologies overcomes these limitations by connecting end devices directly to base stations, obviating the need for the dense and expensive deployments. As opposed to the mesh topology, the devices need not to waste precious energy in busy-listening to other devices.

2) *Duty Cycle*

Radio duty cycling allows LPWA end devices to turn off their transceivers, when not required. Only when the data is to be transmitted or received, the transceiver is turned on.

Regional regulations on sharing spectrum may limit the time a single transmitter can occupy to assure its coexistence with other devices sharing the same channel.

3) Simple Medium Access

Most-widely used Medium Access Control protocols for cellular networks or short range wireless networks are too complex for LPWA technologies. Tight synchronization needed by these schemes is difficult to be met by ultra-low-cost end devices having low quality cheap oscillators. LPWA technologies cannot usually afford this excessive signaling overhead of CMSA/CA. Moost of the LPWA technologies uses ALOHA. Simplicity of ALOHA is thought to keep design of transceiver simple and low cost.

4) Offloading Complexity From End Devices

LPWA technologies simplify the design of end devices by offloading complex tasks to the base stations or to the backend system. This allows end devices to send data using any available channel or orthogonal signal and still reach the base station without need for expensive signaling to initiate communication.

C. Low Cost

LPWA technologies adopt several ways to reduce the capital expenses (CAPEX) and operating expenses (OPEX) for both the end-users and network operators.

1) Reduction in Hardware Complexity

LPWA transceivers need to process less complex waveforms which enables them to reduce transceiver footprint.

2) Minimum Infrastructure

A single LPWA base station connects tens of thousands of end devices distributed over several kilometers, significantly reducing the costs for network operators.

3) Using License-Free or Owned Licensed Bands

Most LPWA technologies considered deployment in the license-exempt bands including the industrial, scientific and medical band which enables low cost deployment and short time to market.

D. Scalibility

LPWA technologies support massive number of devices sending low traffic volumes.

1) Diversity Techniques

*E*fficient exploitation of diversity in channel, time, space, and hardware is vital. Much of this is achieved by more powerful components in networks such as base stations and backend systems.

2) Densification

LPWA networks, like traditional cellular networks, will resort to dense deployments of base stations.

III. PROPRIETARY TECHNOLOGIES

Researchers highlight and compare emerging proprietary technologies and their technical aspects summarized in Table 1.

A. Sigfox

Sigfox is partnership with other network operators offers an end-to-end LPWA connectivity solution based on its patented technologies. They deploy the proprietary base stations. The end devices connect to these base stations using Binary Phase Shift Keying modulation in an ultra-narrow sub-GHZ ISM band resulting in high receiver sensitivity, ultra-low power consumption in expense of maximum throughput of only 100 bps. The number and size of messages over the uplink are limited to 140 12-byte messages per day and 4 8-bytes per day over the downlink. A single message from an end device can be transmitted multiple times over different frequency channels to increase reliability.

B. LoRa

LoRa is a physical layer technology that modulates the signals in sub-GHz ISM band using a proprietary spread spectrum technique. The resulting signal has noise like properties ehich enables resilience to interference and noise. LORa supports multiple spreading factors to decide the tradeoff between range and data rate. The data rate ranges from 300 bps to 37.5 kbps depending on spreading factor.

LoRaWAN is an open standard defining architecture and layers above the LoRa physical layer designed by LoRa Allience.

C. INGENU

INGENU unlike most other technologies does not rely on better propagation properties of sub-GHz band. Instead it operates in 2.4 GHz ISM band and leverages more relaxed regulations. INGENU uses a patented physical access scheme named as Random Phase Multiple Access Direct Sequence Spread Spectrum which it employs for uplink communication only.

IV. STANDARDS

Standardization process is executed by different standardization organizations such as Institute of Electrical and Electronics Engineers (IEEE), European Telecommunications Standard Institute (ETSI), and The Third Generation Partnership Project (3GPP) with relevant parties in an industry, WEIGHTLESS-SIG, LoRa^{TM} Alliance and DASH7 Alliance to produce globally-applicable standards for LPWA technologies. In the long haul, it is expected that diversity of SDOs and SIGs objectives will reduce the separation of LPWA market and technologies.

A. IEEE

IEEE is working on their 802.15.4 [52] and 802.11 [53] standards with new specifications for the physical and the MAC layers to extending range and reducing power consumption. These standards are briefly described.

1) *IEEE 802.15.4k (Low Energy, Critical Infrastructure Monitoring Networks)*: IEEE 802.15.4k Task Group (TG4k) proposes the standard for LECIM applications to operate in

TABLE I
TECHNICAL SPECIFICATIONS OF VARIOUS LPWA TECHNOLOGIES (?=NOT KNOWN)

	SIGFOX	LORAWAN	INGENU	TELENSA
Modulation	UNB DBPSK(UL), GFSK(DL)	CSS	RPMA-DSSS(UL), CDMA(DL)	UNB 2-FSK
Band	SUB-GHZ ISM:EU (868MHz), US(902MHz)	SUB-GHZ ISM:EU (433MHz 868MHz), US (915MHz), Asia (430MHz)	ISM 2.4GHz	SUB-GHZ bands including ISM:EU (868MHz), US (915MHz), Asia (430MHz)
Data rate	100 bps(UL), 600 bps(DL)	0.3-37.5 kbps (LoRa), 50 kbps (FSK)	78kbps (UL), 19.5 kbps(DL) [39]	62.5 bps(UL), 500 bps(DL)
Range	10 km (URBAN), 50 km (RURAL)	5 km(URBAN), 15 km (RURAL)	15 km (URBAN)	1 km (URBAN)
Num. of channels / orthogonal signals	360 channels	10 in EU, 64+8(UL) and 8(DL) in US plus multiple SFs	40 1MHz channels, up to 1200 signals per channel	multiple channels
Link symmetry	✗	✓	✗	✗
Forward error correction	✗	✓	✓	✓
MAC	unslotted ALOHA	unslotted ALOHA	CDMA-like	?
Topology	star	star of stars	star, tree	star
Adaptive Data Rate	✗	✓	✓	✗
Payload length	12B(UL), 8B(DL)	up to 250B (depends on SF & region)	10KB	?
Handover	end devices do not join a single base station	end devices do not join a single base station	✓	?
Authentication & encryption	encryption not supported	AES 128b	16B hash, AES 256b	?
Over the air updates	✗	✓	✓	✓
SLA support	✗	✗	✗	✗
Localization	✗	✓	✗	✗

the ISM bands (SUB-GHZ and 2.4 GHz). Since the earlier standard does not support the short range LWPA technologies, IEEE 802.15.4k fills the gaps with for PHY layer and MAC layer.

2) IEEE 802.11 (Wireless Local Area Networks): In IoT, WLAN technologies made by the IEEE 802.11 Task Group AH (TGah) and the IEEE 802.11 Topic Interest Group (TIG) are remarkable to extend ranges and decrease the power consumption. IEEE 802.11ah specifications as TGah [57] proposed are developed for long range Wi-Fi operation in SUB-GHZ ISM band. Certain new features were expanded to achieve 1 km range in outdoor environments where the data rate in excess of 100 kbps. At the MAC layer, overheads combined with frames, headers and beacons in order to reduced battery powered operations.

3) IEEE 802.15.4g (Low-Data-Rate, Wireless, Smart Metering Utility Networks: IEEE 802.15 WPAN task group 4g (TG4g) proposes to develop the short range of IEEE 802.15.4 base standard. Proposed standard is extended for process-control applications such as smart metering networks like large number of fixed end devices deployed across cities or countries to support multiple data rates ranging from 40 kbps to 1 Mbps across different regions.

B. ETSI

ETSI is working on standardization of a bidirectional low data rate LPWA standard. The main target of this standardization is to reduce the electromagnetic radiation on the air interfaces by exploiting short payload sizes and low data rates of M2M/IoT communication. Apart from these, many interfaces and protocols are defined by LTN for end-devices, base stations, network server, and operational and business management systems. Also SIGFOX, TELENSA, and Semtech are actively involved with ETSI for standardization of their technologies.

C. 3GPP

3GPP is working on cellular standards to strip complexity and cost, improve the range and signal penetration, and prolong the battery lifetime in IoT market.

Long Term Evolution (LTE) enhancements for Machine Type Communications (eMTC), Extended Coverage GSM (EC-GSM), and Narrow-Band IoT (NB-IoT) provides different trade-offs between cost, coverage, data rate, and power consumption in order to fill the gaps of IoT and M2M applications.

1) LTE Enhancements for Machine Type Communications (eMTC): Power Saving Mode (PSM) and extended Discontinuous Reception (eDRx) are proposed to extend the battery lifetime for eMTC. During the process, end devices enters in a deep sleep mode for hours or even days without losing their network registration.

2) *EC-GSM:* Extended coverage GSM (EC-GSM) standard is proposed to to extend the GSM coverage by +20dB using SUB-GHZ band for better signal penetration in indoor environments.

3) *NB-IoT:* The target of NB-IoT is to enable deployment flexibility, long battery life, low device cost and complexity and signal coverage extension with GSM, GPRS and LTE but not in 3G.

D. IEFT

IETF is working on standardizing end-to-end IP-based connectivity for ultra-low power devices and applications for LPWA technologies. IETF group aims to handle more specific technical problems to be addressed as Header compression, Fragmentation and reassembly, Management, Security, integrity, and privacy.

E. LoRa Allience

LoRa is a appropriate physical layer defined by LoRa^{TM} Alliance under LoRaWAN^{TM} Specification for LPWA connectivity. LORAWAN standard uses ALOHA scheme at the MAC layer to enable multiple devices to communicate at the same time but using different channels or orthogonal codes. To preserve the privacy of application data symmetric-key cryptography is preferred to authentication of end devices with the network.

F. WEIGHTLESS-SIG

WEIGHTLESS Special Interest Group [16] is working on three open LPWA standards where these standards both work in license-free and licensed spectrum. WEIGHTLESS-W has outstanding signal propagation properties of TV white-spaces with supporting diverse modulation schemes and wide range of spreading factors.

WEIGHTLESS-N is expanded for one-way communication from end devices to a base station with using DBPSK modulation scheme in SUB-GHZ bands where WEIGHTLESS-P provides two-way connectivity with two non-proprietary physical layers.

G. DASH7 Alliance

DASH7 is working on to provide mid-range connectivity to low-power sensors and actuators for active radio frequency identification (RFID) devices. DASH7 has some differences compared to other LWPA technologies that it uses tree topology as well as star layout, its MAC protocol forces the end devices to check the channel periodically for possible downlink transmissions, it defines a complete network stack.

V. CHALLENGES AND OPEN RESEARCH DIRECTIONS

Although, there are many standards and already developed technologies for LPWAN communication systems, there still exists some open research directions either limiting use case implementation.

A. Scaling Networks to Massive Number of Devices

Scalability is a very important design criteria as any of LPWAN standards are expected to be scaled from several devices to thousands of devices with a variety of geographical areas. Another important point is management of cross-technology interference especially being implemented in unlicensed bands.

MAC access protocols are re-used from existing ones with least complexity. However, ALOHA & basic CSMA access methods limits the number of attached devices for IoT devices. Further study on MAC layer is crucial to enable live network scalability of LPWAN for different use cases.

B. Interference Control and Mitigation

Interference control is one of the biggest design problems in wireless communication networks. IoT devices are expected to grow exponentially, Ericsson forecasts 50B devices to be connected in 2023. This brings the problem of interference for LPWAN either self-interference of proposed technology or cross technology. Hence, allocation of shared resources as time, frequency and code is crucial. As well, modulation techniques shall be studied well to minimize interference.

C. High Data-Rate Modulation Techniques

Current LPWA technologies compromise on data rates to increase coverage which reduces the number of use cases can be implemented. Further study on modulation and channel coding techniques are very important to achieve higher level of data rates without significant decrease in coverage or increase in power consumption.

D. Interoperability Between Different LPWA Technologies

There are several LPWAN technologies available which brings interoperability issues in mind. Different technologies have pros and cons over different use cases which would require co-existence of those in the same network. Therefore, standardization efforts are very important for LPWAN which is expected to clearly define open reference points and functional roles for interoperability. Efforts taken by 3GPP, ETSI, IEEE & IEFT are followed closely by technology investors.

E. Localization

Successful estimation of device location expoits many use cases for LPWAN especially shipment, kids, wildlife, etc. So accurate estimation of device location achieves valuable information. However current wireless technologies require strong signal level from several base stations to provide such an information. This contradicts with LPWAN low cost environment. Location estimation techniques with lower base station signals and less frequent tracking updates increase usability of this feature for low power end devices.

F. LPWA Test Beds & Tools

Live network performance and cross technology interaction are not measurable patterns in lab environments and using theorical outputs. Hence relevant test beds and tools are useful to benchmark system performance for LPWAN technologies for different use cases. Currently, there are only few investments for high scale test beds especially for smart city solutions. Access to test beds and development of test tools would speed up both deployment and evolvement of LPWAN technologies as facing new problems will conduct new research topics.

G.Authentication, Security & Privacy

Security is a critical feature for recent communication systems and LPWAN technologies are expected to ensure secure & private communication not less than most recent communication systems as cellular (2G, 3G, 4G) , Wi-Fi networks. On the other hand, due to low cost and power consumption constraints those need to have simpler but not less powerful security mechanism.

Another important point is capability OTA updates which is crucial to update systems especially distributed over a large distant area. This ensures systems has most recent firmware with up to date features and security profile.

H.Support for Service Level Agreements

Any commercial solution requires service level agreements (SLA) set between service owner and customer to ensure service quality. However, few of LPWAN technologies mention about SLAs currently. Another main issue is; usage of unlicensed bands make it harder to set those due to public usage of band which could cause significant interference on communication. Efforts taken by 3GPP is crucial on this topic and other standart development organizations are expected to follow especially when NB-IoT specifications are finalized.

I. Support for Data Analytics

Data analytics provide valuable information to service providers in case of customer behaviors. They would turn this into revenue increase opportunity with identifying end-user behaviors. Currently, LPWAN does not have significant specifications for data analytics and this is a hot topic to exploit further capabilities of LPWAN systems.

As well there are other important research topics as link optimizations & adaptability, co-existence of LPWAN technologies with other wireless networks and mobility/roaming. These also needs further attention to enhance technologies and set standards to make LPWAN systems suitable with greater variety of use cases.

VI. BUSINESS CONSIDERATIONS

Each technology has pros and cons, there is not a winner among all. This situation makes service providers confused to decide on investment. As a result, it makes LPWAN technologies to evolve slower than expected. Another main issue is the capital expenditure of these technologies which would have a return in a very long period as foreseen use cases are low ARPU ones, M2M communication. So, service providers would like to use existing resources as frequency band, access technology (2G, 4G, etc.) where possible.

From this perspective LPWAN designs on top of existing network architecture seems to have an advantage over other however LoRA, SiGFOX and INGENU leads the market today due to draft state standards of ETSI & 3GPP.

VII. CONCLUSION

In this paper, low power wide area network technologies and standardization efforts are briefly surveyed. It is seen that low power consumption; high coverage area and inexpensive end terminal connectivity are main principles of LPWAN communication systems.

Even though there are several kinds of implementations, use cases are few and limitations of those techniques does not bring significant constraints yet. However, it is clearly seen that further survey required especially on IP header compression, simple and effective authorization schemas, security and encryption, MAC access techniques. Rather than using existing protocol suites, newly surveyed protocols built for IoT/LPWAN ecosystem would increase number of use cases and avoid observed limitations. Another issue on LPWAN is variety of technologies and standardization efforts. Currently, ISPs and vendors are investing in different technologies which slows down overall evolution speed and raise inter-operability issues in between.

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