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Comparative Study of LPWAN Technologies on Unlicensed Bands for M2M Communication in the IoT: beyond LoRa and LoRaWAN

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Abstract

Low power wide area networks (LPWAN) are widely used in IoT applications as they offer low power consumption and long-range communication. LoRaWAN and SigFox have taken the top positions in the unlicensed ISM bands, while LTE-M and NB-IoT have emerged within cellular networks. We focus on unlicensed bands operation because of their availability for both private and public use with one's own infrastructure. New technologies have since been developed to overcome limitations of LoRaWAN and SigFox, based on LoRa or other modulation techniques, and are finding their way mainly into the industrial IoT. These include Symphony Link or Ingenu RPMA. To the best of our knowledge, previous works have not been focused on comparing LPWAN technologies in-depth including alternatives to the link and network layers over LoRa other than LoRaWAN. This paper provides a detailed comparative study of these technologies and potential application scenarios. We defend that LoRaWAN is the most suitable for small-scale or public deployments, while Symphony Link provides a robust solution for industrial environments. SigFox is one the most widely deployed networks; and RPMA has the advantage of using the 2.4GHz band, equally regulated in most countries.

Keywords: IoT; IIoT; M2M Communication; LoRa; SigFox; LoRaWAN; LPWAN; Symphony Link; Ingenu; RPMA; Smart City; Industry 4.0;

1. Introduction

With the rapidly growing number of devices being deployed as part of the Internet of Things (IoT), power consumption and battery life are becoming increasingly important in multiple application scenarios. In cases where data acquisition is sparse in time, transmitting data easily becomes the most power consuming factor in passive sensor nodes. Low power wide area networks (LPWAN) not only enable very low power but also long-range and low-cost

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machine-to-machine (M2M) communication. This permits the deployment of end-devices with battery lives spanning years or decades [1]. The development of new LPWAN technologies has brought new IoT application scenarios.

Low power and long-range communication have evident applications in rural areas where cell network coverage is poor and deploying infrastructure for Wi-Fi or similar networks might be costly due to challenging terrain or scattering of sensor nodes over large areas. However, while LPWANs have been leveraged for a variety of industrial applications related to farming and agriculture, most of the public LoRaWAN gateways are in urban areas [2]. Applications in a metropolitan context include diverse use cases such as smart parking, flood monitoring, weather stations, infrastructure monitoring, smart metering, and lightning or waste management [3, 4, 5]. LoRaWAN and SigFox are the two most popular LPWAN solutions at the moment. LoRaWAN is an open standard for the link and network layers which operates on top of LoRa as the physical layer [6]. SigFox was the first LPWAN to be introduced for the IoT (2009). More recently, new LPWAN technologies have emerged. Symphony Link is a proprietary solution that uses the LoRa modulation with frequency hopping to avoid any duty cycle limitations [7]. Weightless and Ingenu RPMA LPWAN technologies also take advantage of unlicensed radio bands for long-range and low power transmission.

LPWAN technologies have been widely studied in recent years [8, 9, 10, 11]. Previous work has been mostly focused on LoRaWAN and Sigfox. To the extent of our knowledge, there is no technical comparison of Symphony Link with LoRaWAN and Sigfox. Though mentioned by some researchers [12], it has not been widely used for research purposes. Patel *et al.* have performed an experimental study to analyze the performance of Symphony Link in a mobile end-device [13]. However, the authors do not explain the technology behind the application, nor do they compare the performance to other LPWAN solutions. While we do not carry out comparative experimental studies in this paper, we have put an emphasis on summarizing the best LPWAN solution for different applications in the IoT. Mekki *et al.* performed a technical comparative study of LoRa, Sigfox, and NB-IoT, concluding that one advantage of LoRa over Sigfox was the option to deploy local networks [14]. In our work, we compare these with Symphony Link as an alternative for the link and network layers over LoRa. Ismail *et al.* discussed the opportunities and challenges of LoRa, Sigfox, IQRF, RPMA, Telensa, Dash7, Weightless-N, Weightless-P and SNOW [15]. The authors provide a clear overview of the different technologies and potential applications. However, we put more focus on the technical details of the most predominant cases and provide consistent arguments on which are the benefits and drawbacks of each technology for different applications. Raza *et al.* provided an exhaustive description of several LPWA networks, including cellular standards and technologies for unlicensed ISM bands [1].

In this paper, we focus on a more reduced number of technologies that represent LPWAN technology. LoRaWAN as an open network standard and Symphony Link as an advanced proprietary standard over LoRa. Sigfox because of its wide availability in many countries, and ease of use via a subscription payment, and Ingenu RPMA because its technology is radically different from most LPWANs, and operates in a different radio band.

2. LoRa Modulation at the Physical Layer

LoRa (long-range) is a patented modulation technology for wireless communications acquired by Semtech Corporation in 2012 [16]. LoRa was designed to allow low-power, low-rate, long-range transmissions with very-long-range in rural areas or line-of-sight situations up to 10 or 20km. LoRa is designed to work on unlicensed frequency bands such as 433MHz, 868MHz or 915MHz, depending on the geographical location and the corresponding regulations. LoRa refers to the physical layer, does not include any form of encryption, and defines a spread spectrum modulation technique based on chirp spread spectrum (CSS) technology [17]. CSS, or linear frequency sweeping (LFS), modulation has theoretical superior characteristics to more traditional modulation techniques such as frequency or phase-shift keying (FSK/PSK) in the cases of a partially coherent and fading channel [18].

Semtech's LoRa modulation gives a bit rate R_b proportional to the bandwidth and inversely proportional to 2^{SF}, where SF is the spreading factor taking values from 7 to 12. A single LoRa chirp codes a number of bits equal to the spreading factor. Thus, even if the data rate is halved when the spreading factor increases one unit, the number of bits encoded in each symbol is also increased by one[19]. This is achieved by coding each possible bit value into a shifted chirp, creating a sharp change in the frequency trajectory. The actual transmission bit rate changes when taking into account that LoRa applies forward error correction by increasing the redundancy in the transmitted payload. The final bit rate is multiplied by a factor $4/(4 + CR)$, where CR is the coding rate taking values from 1 to 4. The coding rate represents the number of bits that actually contain data, as compared to the total number of transmitted bits.

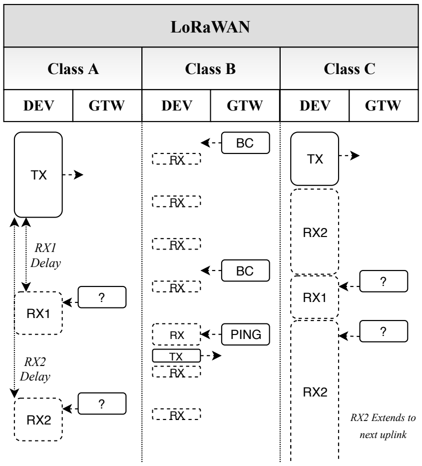

Fig. 1: Tx/Rx Windows for LoRaWAN Classes A, B and C. Packets with (?) are optional downlinks.

LoRaWAN	Symphony Link	SIGFOX	WEIGHT LESS-P	WEIGHT LESS-N	WEIGHT LESS-W	INGENU
LoRa		DBPSK +GFSK	FDMA +TDMA	BPSK	GMSK +QPSK	RPMA
ISM Sub-Gigahertz					TV Bands	2.4GHz

Fig. 2: Different LPWAN solutions and their modulation schemes. From top to bottom, the rows reference to network and link layers, physical layer and frequency bands.

Table 1: LoRaWAN vs. Symphony Link

	LoRaWAN	**Symphony Link**
Acknowledgement	Limited	Always
Bidirectional Link	Mostly uplink (Class A)	Yes
Built-in Adaptive Data Rate	No	Yes
Duty Cycle Limitations	Yes (1%)	No
Encryption Scheme	AES128	PK (needs setup)
Repeaters	Not integrated	Yes
Over-the-air updates	Limited (one-by-one)	Yes, multi-cast
Protocol	Aloha (Class A)	Synchronous
Licensed	No - Open standard	Yes - Proprietary

One of the main advantages of LoRa is the high receiver sensitivity and, therefore, a large communication link budget. This enables very long-range transmissions. Typical SNR levels for spreading factors 10 and 12 when using LoRa modulation are -20dB and -15dB, obtaining receiver sensitivities of -134dBm and -129dBm, respectively. These values are barely comparable to the typical sensitivity of Wi-Fi or Bluetooth receivers, which often is in the range of -40dBm to -80dBm [20]. However, we should note that the data rates that are achievable with LoRa modulation are several orders of magnitude lower. Time on air is also significantly larger. Chirps are transmitted at a frequency equivalent to the signal bandwidth. A symbol is encoded in 2^{SF} chirps, with time on air $T_{sym} = 2^{SF}/BW$.

The key properties of LoRa modulation are (1) its scalable bandwidth and frequency, easily changing from narrowband hoping to wideband; (2) resistance to Doppler shift; (3) relatively high immunity to fading or multi-path, especially in dense urban scenarios, and (4) robustness to interference. This is on top of the very-long-range, low transmission power required with constant envelope, and increased capacity because of the orthogonality of signals with different spreading factors. The parameters that have the most impact on the transmission reliability and communication range are the bandwidth (BW), spreading factor (SF), and coding rate (CR) [21, 22, 23, 24]. LoRa is particularly resilient to interference and packet collision with low packet loss rate in nominal link conditions.

Taking all the above into account, we can outline the advantages of LoRa for the IoT as enablers of (1) long-range transmissions over 10km in line-of-sight; (2) low cost deployment of nodes and gateways due to the low cost of LoRa transceivers and a reduced number of gateways compared to Wi-Fi or Bluetooth solutions; (3) adaptable bandwidth, coding rate and spreading factor to increase reliability in different channel conditions and allow multi-channel transceivers to operate in parallel, enabling a single gateway to receive data from a very large number of nodes, even in the order of thousands; (4) very low energy consumption for battery-powered devices; and (5) orthogonal packet transmission using different spreading factors without compromising transmission reliability.

3. Link and Network Layers over LoRa

The LoRa specification just provides the physical layer for radio communication. LoRaWAN is the most popular media access control (MAC) protocol for wide area networks, mainly used on top of LoRa but also suitable for FSK modulation [6]. In this section, we introduce the LoRaWAN protocol and discuss its alternatives.

LoRaWAN

LoRaWAN is, fundamentally, a network protocol that has been designed keeping in mind that in most use cases of LoRa devices are battery-powered and therefore energy consumption must be kept as low as possible. Moreover, these devices can be either fixed or mobile, and therefore would not build a connection with a specific gateway. The network topology of LoRaWAN is a star network, where several end-devices transmit to a given gateway. In fact, devices broadcast their transmissions and might be received by several gateways. Then, back-end servers where all gateways are connected to make an automatic decision on which gateway handles the received packets. Uplink transmissions are considered predominant in LoRaWAN, and therefore have preference over downlink. Because LoRa focuses on battery-powered end-devices, a large number of transmissions being received at the node would rapidly increase the power consumption, due to long listening times waiting for a package to arrive. LoRaWAN takes this into account by defining different classes of communication depending on the energy consumption constraints of different end-devices. The protocol tackles this by defining three different classes of connected end-devices with an incremental number of features: (1) Class A devices, with the basic set of features that all devices must implement; (2) Class B devices, with scheduled listening windows; and (3) Class C devices, for bi-directional communication at any time.

The transmitting and receiving windows for each of the three LoRaWAN end-device classes are illustrated in Figure 1. Class 1 devices are those with more strict requirements in terms of power consumption. To minimize the opening time for receiving windows, the LoRaWAN specification defines two short windows, each of them starting at a predefined time from the end of the transmission. The first receiving window, RX1, is configured with frequency and data rate parameters that depend on those used for the uplink based on a given, predefined function. By default, these are parameters are simply the same than in the last uplink transmission. The second receiving window is configurable with parameters that can be set through different LoRaWAN MAC commands. The default values are region specific and fixed, independent of the parameters used during the uplink. This is similar to the Aloha method, in which acknowledgement is not expected for every transmitted message [25]. As such, Class A devices do not automatically receive receipt acknowledgement unless specifically requested. Moreover, these devices must not start a new uplink transmission until the second receiving window has been closed. An application that needs to transmit data back to the end-device can do so only in the fixed windows after an uplink message. This means that the application needs to wait for the end-device to transmit in the first place, and limits the amount of data that can be sent back. Class B devices address this problem by scheduling receiving windows with a given period of time. These windows are defined by beacons being transmitted by all gateways in the network, which must be accordingly synchronized to transmit at the same time. End-devices always register to a LoRaWAN network as Class A and then request, through MAC commands, to change their status to Class B. If the end-device does not receive a beacon during a given period, then it must switch back to Class A automatically. In Figure 1, ping messages from gateways can be sent at any time corresponding to the scheduled RX windows. RX windows close shortly after being opened if no preamble is detected, and remain open until the full message has been decoded otherwise. Ping messages are meant to track the location of the end-device and switch the assigned gateway if necessary for any incoming downlink transmission. Class B devices send a short reply after a ping message. For less power-constrained devices, the LoRaWAN specification defines the Class C. Also known as continuously listening end-devices, Class C devices that have sufficient power shall listen with RX2 window parameters (as defined for Class A) as often as possible, with RX1 windows still opening after each uplink transmission. Gateways can, therefore, send any downlink transmission at any time, taking into account the last uplink time so that modulation parameters are chosen correspondingly to those of window RX1 or RX2.

Due to the relatively limited number of channels in the frequencies at which LoRa operates and the local regulations that apply in different countries or geographic areas, LoRaWAN defines three basic rules for all connected devices to comply with: (1) Devices must change the LoRa modulation parameters in order to use different channels for different transmissions, therefore increasing robustness towards interference; (2) individual transmission time on air must respect the limits set by corresponding local regulations; and (3) total duty cycle of consecutive transmissions must respect limits set either by LoRaWAN or local regulations, whichever is more restrictive. Through these rules, LoRaWAN allows a more uniform usage of the available spectrum while ensuring that all connected devices will have enough open time and frequency for transmitting, reducing the packet error rate. This becomes particularly important for Class A devices that do not necessarily receive acknowledgement for the transmitted data.

Symphony Link

LoRaWAN is the most popular network protocol that operates on top of LoRa. However, other open source and proprietary solutions have been designed to tackle the limitations of LoRaWAN. Symphony Link, developed by Link Labs, overcomes some of the limitations of LoRaWAN [26, 7]. Symphony Link puts a stronger focus on industrial applications and provides a solution to eliminate the duty cycle limits by using frequency hopping and different available frequencies. It also provides built-in support for repeaters to increase the range of a single gateway without trading off total bandwidth. Another strong point of Symphony Link is that it allows one-to-many communication from a gateway to end nodes. This simplifies and increases the speed of over-the-air updates or broadcast messages.

The Symphony Link protocol varies significantly with respect to LoRaWAN. There are no device classes. Instead all devices operate under the same conditions. Both gateways and end-devices perform interference scans to select the transmission channels. Gateways select a 500 KHz channel (or 125 KHz in Europe) and transmit beacons with a 0.5 Hz frequency. The beacons are encrypted by a network id, which needs to be configured in the end devices before connecting. Gateways broadcast information about the numbers of channels being used during transmission for the frequency hopping scheme. These can be configured as 1, 8 or 64 channel gateways, and repeaters and end-nodes adapt to this setup. Gateways also transmit information about the quality of service (QOS). This is useful for choosing which packets are transmitted by end-devices if the network is congested and more priority is given to some information. With Symphony Link, nodes can save power by adapting the transmit power and LoRa modulation through the spreading factor based on the received signal power. While this can be done in LoRaWAN, the lack of frequent downlink messages for standard Class A devices makes the estimation harder.

The advantages of Symphony Link over LoRaWAN can be summarized as (1) guaranteed message receipt, (2) firmware updates with multicasting, (3) duty cycle limit removal, (4) built-in support for repeaters, (5) adaptive data rate with dynamic modulation and power adjusted with transmit power and spreading factor calculated based on reverse link, (6) public-key based encryption, (7) higher capacity and less collisions in multiple gateway environments. The sensitivity of Symphony Link is basically the same than LoRaWAN, as well as the frequencies in which it operates. In terms of open access, the LoRaWAN is an open standard while Symphony Link is proprietary. Deploying private networks is possible with both protocols but operating a public LoRaWAN network requires a network ID given by the LoRa Alliance, which are available to contributor members or above.

MoT: MAC on Time

Hassan *et al.* have developed a MAC protocol that is based on LoRa for the physical layer, with a focus on reducing energy consumption, enabling scalable networks with fair usage and maximize capacity [27]. The authors have designed a protocol called MoT (MAC on Time), with guaranteed package delivery and improved bandwidth utilization. One key difference is that the time that a node will stay idle or in sleep mode will be decided by the network and communicated from the gateway via the packet acknowledgement. With this approach, MoT overcomes clock drifts with a centralized scheduling. The performance of the protocol has been tested through multiple simulations. MoT has proved to be able to provide 4 to 15 times more network capacity and better latency than LoRaWAN.

4. Low-power, long-range modulation alternatives to LoRa

LoRaWAN and Symphony Link are the most widely used network layers that operate with LoRa modulation. However, other LPWAN technologies rely on different frequency bands or use a distinct modulation scheme.

SigFox

Sigfox provides both a modulation technology for the physical layer and a media access control protocol on top of it [28]. Moreover, Sigfox partners with operators to build its network infrastructure and provide it as a service. At the physical layer, and compared to LoRa's use of CSS, Sigfox is based on differential binary phase-shift keying (DBPSK) and Gaussian frequency shift keying (GFSK). The data is transmitted in channels of only 100 Hz of bandwidth (ultra-narrowband, UNB) in order to minimize noise, and a total 192 KHz of the spectrum is used. Because device and network are not synchronized, in pursuance of higher quality of service (QOS), data transmission is done using frequency hopping and replicating the message twice, for a total of three random frequencies. As in LoRaWAN, end-devices are not registered to a single gateway. An average of 3 base stations or gateways receive each message, further increasing the QOS with spatial diversity on top of time and frequency diversity. Sigfox restricts the length of payloads to 12 bytes and transmission speed is of 100 bps. The number of daily messages is limited to 140, in order to comply with the 1% duty cycle limitation set by European regulations. Sigfox works on the 902 MHz band in North America and 868MHz in Europe. In the US, FCC regulations limit the time-on-air of UNB signals, so Sigfox uses a different implementation with frequency hopping [29]. All data goes through the Sigfox Cloud servers and is available to end-users via their web-interface and a REST API. The power consumption, communication range, and data exchange process is overall similar to the case of LoRaWAN Class A devices. Data encryption is based on AES, without impact on the size of the payload, and without key exchange over-the-air. Instead, each device is provided with a symmetrical authentication key when it is manufactured.

In summary, the advantages of Sigfox over other LPWAN solutions are the wide coverage of its network, the broad range of compatible hardware from different vendors and their power efficiency. It is most suitable for metering applications with very time sparse sampling. Sigfox's main limitation is the maximum number of daily messages, especially downlink transmissions. Therefore, it is not recommended for applications that need to access online data. Furthermore, Sigfox is not an open protocol and its built-in security is minimal. Private network deployment is not possible and Sigfox operators charge a fee per device, so its usage is more similar to a cellular network. In terms of availability and coverage, SigFox has strong business traction and nearly countrywide coverage in central Europe.

Ingenu RPMA

Ingenu RPMA is a technology built from scratch with advanced modulation techniques that was designed with a focus on minimizing the total cost of ownership while increasing the range of a base station and link capacity of LoRa and Sigfox. Random Phase Multiple Access (RPMA) is a technology patented in 2010 by Ingenu [30]. On top of it, Ingenu has developed LPWAN technology that allows much higher link capacity than LoRa or Sigfox. It works on the 2.4 GHz ISM band, in contrast with most LPWAN technologies using sub-gigahertz frequencies. This has the benefit of being equivalently regulated over the world. However, the 2.4 GHz is widely used by many other technologies, including Wi-Fi and Bluetooth, and therefore interference is more probable as the spectrum is more congested.

RPMA is based on the direct-sequence spread spectrum (DSSS) modulation technique. Communication is two-way, and devices perform scanning in the background with handover so that the best access point is chosen for each transmission. Gold codes in base stations or gateways are configurable to eliminate ambiguity. Its downlink capacity is much larger than in the case of Symphony Link due to an adaptive spreading factor methodology. One of the key advantages of RPMA over LoRa and Sigfox is the network capacity. Ingenu claims that a single gateway can handle up to 2 million devices per access point [31]. While LoRa receivers can demodulate signals with different bandwidths or different spreading factors simultaneously, RPMA supports parallel demodulation of up to 1200 signals on the same frequency. As with Symphony Link, Ingenu requires all gateways in the same network to be synchronized, so that end-devices are aligned in time with them. Another similarity is the adaptive spreading factor of the transmission to reduce the power consumption based on channel conditions at each transmission time. While this could be done with LoRaWAN or Sigfox, the functionality is not built-in in their modules. In general, Ingenu RPMA offers similar features to Symphony Link. The main differences are its increased capacity per access point and the ISM band used for transmission. RPMA has a higher link budget, longer range in open space, and the 2.4GHz band is regulated consisted through the globe, as compared to sub-gigahertz bands. However, a higher frequency also means that penetration through most materials is less effective. This translates into less range in dense urban areas or large indoors facilities.

Other Alternatives

There are many LPWAN technologies that have been developed for the IoT. Sigfox and Ingenu RPMA are the most popular solutions that do not use LoRa modulation, and we have put a focus on them. However, Weightless technologies are also well known and are summarized here. Weightless, formerly known as Weightless-P, is an open standard developed by the Weightless Special Interest Group. The group initially developed three LPWAN technologies, namely Weightless-W, Weightless-N, and Weightless-P [1]. The N and P versions both use sub-gigahertz bands, with Weightless-N aimed a lower power use with one-way communication and based on narrowband with DPSK modulation. Weightless-P, as with Symphony Link or RPMA, provides packet acknowledgement and two-way communication, with FDMA+TDMA modulation. Weightless-W uses TV bands white spaces.

Considerations

When comparing wireless communication technologies, a common benchmark used as a reference is the maximum data rate. However, in the case of LPWANs, because of the wide range of modulation possibilities for a single technology, this is not an immediate comparison. Moreover, if the amount of data that can be transmitted is limited, then the speed at which it is transmitted remains in the background. LoRaWAN's data rate ranges from 0.3 to 27 kbps depending on the spreading factor and bandwidth. Sigfox's is fixed to 100bps, but this figure is not so important when taking into account the maximum of 140 messages per day. Ingenu RPMA offers the highest data rate when compared to most LPWAN technologies, though the real transmission speed will adapt according to channel conditions.

5. Application Scenarios

LPWANs are being applied in an increasing number of scenarios in the IoT, from smart cities to the industrial IoT [9, 32, 33]. In this section, we discuss the most appropriate LPWAN technology for different applications.

Urban Areas and Smart Cities

In urban areas, power efficiency, ease of deployment and scalability are perhaps the most significant factors when selecting an LPWAN technology. While a minimum range is required in order to keep the number of gateways or base stations reduced. For a smart city, having an open and public network has the benefit of allowing more people and organizations to use it. This can increase the level of technology penetration in the city. With an open network open for local businesses, educational institutions and all citizens, the number of applications can rapidly grow and serve as an economic boost. Therefore, not only does it serve the purpose of providing connectivity through the metropolitan area, but it also increases the interaction with local businesses and citizens. Deploying a private network such as Symphony Link or Ingenu with less widely available hardware and a smaller community of users would be beneficial for cities only for specific applications where more control over the network might be required. Taking these considerations into account, we propose LoRaWAN as the first LPWAN network solution to be considered for a Smart City. This has already been done in Amsterdam or Bristol [2]. The economic and social benefits can rapidly overcome the small investment in infrastructure required. Sigfox is an option to consider if a lower cost is required. However, recurrent payments over a long usage of Sigfox might sum more than the investment needed to deploy a LoRaWAN network.

Industrial Internet of Things

In industrial applications, it is often preferable to deploy a private network. An open network does not meet the requirements for a reliable connection and higher levels of security. Moreover, for applications that may be critical in terms of business performance or safety, it is essential to have full control over the network. Therefore, Sigfox and public LoRaWAN networks would have the disadvantage of being used by multiple users, which increases the probability of packet collision, interference and bandwidth saturation. Moreover, Sigfox and LoRaWAN do not provide acknowledgement and limit the number of transmissions. In an industrial environment, a more flexible solution can be better adapted to the intrinsic dynamic environment. Both Symphony Link and Ingenu allow higher data rates, do not have limitations in the number of messages and provide acknowledgement. Acknowledgements are not critical in metering or similar common urban applications. Nonetheless, a series of undelivered messages in relation to critical processes in a production line might severely affect performance. Additional features such as one-to-many transmissions from gateways in Symphony Link eases the process of updating firmware. While this is not significant in public networks with a large number of different connected devices, in industrial applications there is more homogeneity. In conclusion, we would advise private companies to use Symphony Link or Ingenu RPMA for industrial environments. Both of these technologies have been designed after LoRa and Sigfox were introduced in the market, and therefore have been able to tackle the main problems that they presented while improving the overall network performance.

Farming and Agriculture

In farming and agriculture, LPWANs have a more clear advantage over other technologies such as Wi-Fi or Bluetooth. While the range in urban areas is already much better, it is in rural and open areas where the range of a single gateway can be extended beyond 10km with LoRa and over 30km with Sigfox. Ingenu claims some of its customers reported coverage of 400 square miles per tower in Texas, and they have deployed their Machine Network in the greater Phoenix area (1900 square miles) with 9 access points. Because of low interference in rural areas, any of the technologies presented in this paper can be used effectively for farming or agricultural applications, depending on the requirements. For time sparse data such as measurements of soil moisture and temperature, water levels, gate access control or hourly rain volumes, LoRaWAN and Sigfox can be both used depending on whether Sigfox is available in the area or a new network infrastructure based on LoRaWAN is preferred. In these scenarios, as compared to industrial places that could be situated near urban areas, the probability of interference and packet collision is much lower. For applications that require more frequent data exchanges or downlink capabilities, Symphony Link and Ingenu RPMA could be deployed instead. This includes monitoring of machinery or vehicle tracking. In particular, because of the built-in support for repeaters in Symphony Link, and the relatively low number of devices that would be deployed in farming or agriculture applications, it is a technology that can decrease the overall infrastructure cost. A single base station and a set of repeaters could be used to extend the range to tens of kilometers if the network capacity allows.

6. Conclusion

We have presented a comprehensive LPWAN review, with a focus on technologies that use unlicensed radio bands. From the technical point of view, at the physical layer, Sigfox and Ingenu RPMA use narrowband modulation, while LoRa uses spread spectrum. In urban environments, all of them have a similar range, while uplink capacity of Ingenu RPMA might be larger. However, in the cases of Ingenu and Symphony Link, the downlink activity affects the network capacity. This effect is less noticeable in LoRaWAN Class A and Sigfox due to the limited downlink possibilities. Because of the more recent development of Ingenu and Symphony Link, they have been developed taking into account the drawbacks and main limitations of LoRaWAN and Sigfox. The main advantages can be summarized as full acknowledgement of all messages, support for repeaters and one-to-many downlinks for over-the-air updates, increased data rates and elimination of transmission limitations.

We have defended that LoRaWAN can be the best option for deployment in a smart city or urban areas by public parties. Deploying a LoRaWAN network can enrich the diversity of applications and allow economic growth beyond the initially planned applications. For industrial environments, control over the network is more important and therefore having a private network deployment is preferable. For low volumes of data and low-frequency acquisition, LoRaWAN or Sigfox may be sufficient. For real-time data acquisition Symphony Link and Ingenu are better options.

In conclusion, there is a large number of LPWAN technologies and new ones are being actively developed. The number of applications that these technologies enable grow by the day together with their penetration in society. In this paper, we have covered a small representative subset, with an emphasis on the unlicensed spectrum and introducing a set of technologies that can be of interest for different fields in the IoT. Symphony Link has been barely mentioned as an alternative to LoRaWAN in previous work, and we have put a focus on its benefits and drawbacks.

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