Low Power Wide Area Networks Operating in the ISM Band- Overview and Unresolved Challenges

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Abstract. Today the Internet of Things connects millions of devices around the world, offering access to new services and technology development capabilities. The use of multiple small-sized sensors makes it possible to control and manage different processes in a new, intelligent and flexible way. In this paper a survey of Low Power Wide Area Networks operating in the ISM band is conducted, examining future development trends, major challenges and applications. Using this type of network it becomes possible to transmit information over very long distances, minimize the energy used and deploy huge quantities of sensors over large geographical areas. This paper also presents an overview of RF Data Analytics as a modern technique to enhance the network performance of LPWANs. This can be achieved by examining raw RF data in order to predict the trends that characterise it and subsequently to implement a range of methods and algorithms for interference management and intelligent spectrum utilisation.

Keywords: IoT · LPWAN · WSN

1 Introduction

Thanks to advances in wireless communications, sensors and machine intelligence, the Internet of Things (IoT) is rapidly becoming a reality. In IoT, physical objects can be managed remotely so that they act as access points for various Internet services. However there is still no wireless technology appropriate for all possible scenarios and applications of IoT. Until a comprehensive solution emerges, the industry is focussing on creating solutions that meet the needs of specific market segments. Currently, many hands-on systems use existing cellular technologies. Due to the power requirements of cellular modems and the fact that when operating in continuous mode they consume large amounts of energy, they do not have sufficient long-term battery power to provide the necessary capability for large intelligent sensor networks to process data from measuring devices. Therefore, new wireless technologies, some of them nearing implementation, are being developed.

LPWANs are used for delay-tolerant cases, when high data rates are not required but low power consumption and low cost of infrastructure are of great importance. In this area, the LPWAN technologies meet the needs of many applications for smart cities, smart metering, home automation, wearable electronics, logistics, environmental

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monitoring, etc. In these cases an exchange of small amounts of data is needed and the data rates necessary for reliable communication are very low, which is the main reason why LPWAN technologies have attracted serious interest in the past few years.

The interference and the significant attenuation of the signals are two classic problems in the ISM range used by LPWANs. Along with the interference caused by heterogeneous and homogeneous devices, ISMs also suffer from interference due to coexistence and proximity to other networks. This interference, together with many other problems related to ISM's dynamic nature, can dramatically reduce the quality of service (QoS). Many of the studies have analysed the impact of interference but there is still a need for more in-depth research to study the peculiarities of transmitting signals, channel features and parameters. Interference largely depends on how different technologies coexist. A real challenge is the analysis of different IEEE 802.11 Wireless Local Area Network (WLAN) implementation scenarios operating in one frequency range with non-orthogonal carrier frequencies. In this case, interference management and spectrum utilisation may be accomplished by the development of a cloud architecture for a spectrum monitoring network where the collection, preservation and processing of RF signals or I/Q data in the baseband, as well as the processing of signals and protocols from the higher levels, are carried out entirely in the cloud.

In this paper, an overview of the most important LPWAN technologies is presented with a focus on their basic characteristics, major applications and susceptibility to interference. In addition, a review of RF Data Analytics is also conducted. The latter is an excellent starting point for the development of new resourceful algorithms for spectrum utilisation analysis and hence for more efficient use of the available spectrum, better interference management and transmission quality management.

2 Low Power Wide Area Networks Operating in the ISM Band

LPWAN is gaining increased popularity in industrial and research communities because of its low power, low-cost communication characteristics and long-range communication capabilities: around 10–40 km in rural zones and 1–5 km in urban zones [1]. In addition, these networks are highly energy efficient (up to 10 or more years of battery lifetime) and low-cost, at around the cost of a radio chipset [2]. These promising aspects of LPWANs have encouraged recent experimental studies on their performance in outdoor and indoor environments. LPWANs are highly suitable for IoT applications that need to transmit only small amounts of data but over long distances. Until recently, until 2013, the term "LPWAN" did not even exist. At present, many LPWAN technologies have sprung up in both the licensed and unlicensed frequency ranges. Among them are today's leading LPWAN technologies such as: SigFox, LoRa, and NB-IoT which, apart from individual innovations, also include many technical differences.

The LPWAN technologies being standardised by 3GPP possess several characteristics that make them especially attractive for market devices and applications requiring low mobility and low levels of data transfer:

- *Low power consumption* (to the range of nanoamps) that are required to operate without battery replacement;
- *Optimised data transfer* (supporting small, intermittent blocks of data);
- *Low device unit cost* - the simplicity of LPWAN end-devices makes these networks economically viable;
- *Simplified network topology and deployment* – LPWANs use: (a) narrowband to support a massive number of devices to efficiently utilize the limited spectrum; (b) multiple antenna systems to enable the base stations (BS) to support large numbers of nodes; (c) massively parallel communications in both directions using single antenna systems, thus providing opportunities to scale.
- *Improved outdoor and indoor penetration coverage* compared to existing wide area technologies;
- *Secured connectivity and strong authentication*;

Unlike traditional Wireless Sensor Networks (WSNs) that usually employ mesh topology, the state-of-the-art LPWAN technologies require the setting up of gateways, referred to as concentrators or BSs, to serve end-devices, i.e. end-devices communicate directly to one or more gateways. Depending on the technology, the coverage area of a single gateway may range from hundreds of meters to tens of kilometres and may include thousands or even millions of end-devices. Over the last few years, LPWAN technologies have drawn a lot of attention due to large investment from the private sector.

2.1 LPWANs - Overview and Comparison

LoRaWAN - LoRa Wide Area Networks are a low power specification for IoT devices operating in regional, national or global networks. It is frequency-agnostic and can use the 433, 868 or 915 MHz bands in the ISM (industrial, scientific and medical) range, depending on the region in which it is located. LoRa is the physical layer or wireless modulation that is used to implement a long distance communication link. Data transmission speeds vary from 0.3 kbps to 50 kbps, depending on whether channel aggregation is used. The standard LoRa operates in the 868 MHz (EU)/915 MHz (US) frequency range, at a distance of 2–5 km (urban environment) and up to 15 km (suburban), with a transmission speed not higher than 50 kbps. The advantage of the technology is the ability to achieve long distance connections, with a single base station having the capability to cover hundreds of square kilometres. The size of the covered range is highly dependent on the environment and the presence of obstacles, but LoRa and LoRaWAN have the best power supply organisation when compared to any other standardized communication technology [3].

SigFox - SigFox is a low power wireless communication technology for a diverse range of low-energy objects, such as sensors and M2M applications that send relatively little data. SigFox allows the realization of sensor networks that can run on batteries for several years. It resembles the cellular networks used by mobile operators, but instead of offering services for customers who need a high bandwidth, low jitter and high rate, SigFox provides services to devices. Therefore, the advantages of cellular networks are combined with lower energy consumption and lower cost. A SigFox network consists of cells, each with a gateway that communicates with sensors. It enables the transfer of small amounts of data at distances up to 50 km. Presently there increasing interest in such low power networks that work longer, as they are especially suited for battery-powered devices. SigFox works at the 868 MHz frequency bands in Europe and 915 MHz in the USA, with ranges from 3–10 km (urban), up to 50 km (rural) and provides transmission rates up to 100 bps. SigFox uses the Binary Phase Shift Keying (BPSK) modulation in an ultra-narrow (100 Hz) SUB-GHZ ISM band carrier. Nowadays SigFox works as a bidirectional technology, although with significant link asymmetry [4]. The downlink communication must be accomplished before the uplink communication, then the end-device must wait for a response from the BS. The number and size of the messages over the uplink are limited to 140 12-byte messages per day. Radio access link is asymmetric, allowing transmission of only 48-byte messages per day over the downlink from the BSs to the end-devices. This means that acknowledging every uplink message is not supported. The reliability of the uplink communication can be improved by using time and frequency diversity as well as redundant transmissions. In addition, intelligent support for acknowledgements must be implemented in order to increase the overall network performance.

Weightless - Weightless is a wireless technology introduced by the Weightless Special Interest Group (SIP) [5]. The latter proposed three open LPWAN standards known as Weightless-W, Weightless-N, and Weightless-P. Weightless is based on cognitive radio (Weightless-N, and Weightless-P) and TV white-spaces (Weightless-W) which enable devices to utilize these bands as opportunistic users. Thus a mitigation of inter- and intra-network interference is achieved to the primary user devices, which are defined as licensed owners. Weightless-N is an ultra-narrow band (UNB) standard providing only one-way communication from end-devices to the BS. Thus a significant energy efficiency is achieved, especially when compared to the other Weightless standards. However, Weighless-N has a very limited range of use cases. It uses differential binary phase-shift keying (DBPSK) modulation scheme in Sub-GHz bands. Weightless-P is based on two-way communication with two non-proprietary physical layers. It is based on the widely-used Gaussian minimum shift keying (GMSK) and Quadrature Phase Shift Keying (QPSK) and thus the end-devices do not require a proprietary chipset. Each single 12.5 kHz narrow channel in the SUB-GHZ ISM band offers a data rate in the range of 0.2 kbps to 100 kbps. Weightless-P eliminates the drawback of SigFox and offers full support for acknowledgments and bidirectional communication capabilities, enabling over-the-air upgrades of firmware. Similarly to LoRaWAN, the three Weightless standards employ symmetric key cryptography for the authentication of end-devices and integrity of application data.

DASH7 - the DASH7 Alliance Protocol is a new form of wireless transmission, like Wi-Fi, Bluetooth or ZigBee. DASH7 is the name of the technology promoted by the non-profit consortium named the DASH7 Alliance. Unlike most radio-frequency identification (RFID) technologies, DASH7 offers Tag-to-Tag communication which, combined with a long range and the benefits of 433 MHz signal propagation, makes it an easy substitute for most wireless sensors. DASH7 also supports midrange connectivity for low power sensors [6]. DASH7 communication is based on a narrow band modulation scheme using two-level Gaussian frequency-shift keying (GFSK) in Sub-GHz bands. Compared to other LPWAN technologies, DASH7 has a number of distinguishing differences: the usage of a tree topology by default with an option to also choose star layout; the end-devices are connected to duty-cycling sub-controllers, which then communicate to the BSs, which are always in active mode. The duty-cycling mechanism brings more complexity to the design of the upper layers. Also, the DASH7 media access control (MAC) protocol forces the end-devices to periodically check the channel for possible downlink transmissions, thus adding significant complexity. This results in lower latency for downlink communication compared to other LPWAN technologies but at the expense of higher energy consumption. Moreover, DASH7 defines a complete network stack, enabling applications and end-devices to communicate with each other without having to deal with the intricacies of the underlying physical or MAC layers. DASH7 supports forward error correction and symmetric key cryptography.

Ingenu RPMA - formerly known as On-Ramp Wireless, Ingenu RPMA is a proprietary LPWAN technology which utilizes the 2.4 GHz ISM band (as used by Wi-Fi and Bluetooth), unlike LoRa and SigFox which exploit the 915 MHz ISM band. Thus Ingenu RPMA leverages more relaxed regulations on spectrum use across different regions [7]. For example, the regulations in the USA and Europe do not impose a maximum limit on the duty-cycle for the 2.4 GHz band, enabling higher throughput and more capacity than other technologies operating in the Sub-GHz band. Ingenu RPMA uses star network topology with access nodes (BSs) that act as endpoint coordinators. The end-devices communicate with nodes using a patented Random Phase Multiple Access (RPMA) Direct Sequence Spread Spectrum (DSSS), which is distinguishes them from their competitors. RPMA is only used for transmitting data in the uplink - from the sensor to the BS - whereas a conventional code-division multiple access (CDMA) algorithm is used for the downlink. RPMA provides a better signal-to-noise ratio (SINR) than CDMA, but is also vulnerable in terms of security. RPMA enables multiple transmitters to share a single time slot. However, RPMA first increases the time slot duration of traditional CDMA and then scatters the channel access within this slot by adding a random offset delay for each transmitter. By not granting channel access to the transmitters exactly at once (i.e., at the beginning of a slot), RPMA reduces overlapping between transmitted signals and thus increases SINR for each individual link. On the receiving side, demodulators are used by the BSs in order to decode signals arriving at different times within a slot. Ingenu RPMA is based on bidirectional communication, although with a slight link asymmetry. For downlink communication, BSs spread the signals for individual end-devices and then broadcast them using CDMA. RPMA is reported to achieve up to −142 dBm receiver sensitivity and 168 dB link budget. It is possible to mitigate the interference to nearby devices by adjusting the transmit power of the end-devices. RPMA technology is compliant with the IEEE 802.15.4 k specifications.

Telensa – The Telensa protocol can provide fully bidirectional communication for LPWAN applications incorporating fully designed vertical network stacks with support for integration with third party software [8]. Telensa aims to standardize its technology using ETSI Low Throughput Networks (LTN) specifications for easy integration within applications. Telensa uses the UNB modulation technique, which operates in the licence-free Sub-GHz ISM band at low data rates. A Telensa BS can connect to up to 5000 nodes, and cover 2 km in urban and 4 km in rural areas. The Telensa nodes can continue their functioning even if the connection to their BS is lost, and have an estimated lifetime of 20 years. Telensa currently focuses on a few smart city applications such as intelligent lighting, smart parking, etc. Moreover, it supports integration with third-party applications by providing smart city application programming interfaces (API). Telensa have already deployed millions of nodes over 50 smart city networks globally, mostly in the United Kingdom but also in other cities around the world such as Shanghai, Moscow and Sao Paolo. The Telensa technology does not support indoor communications, which is its significant drawback.

2.2 LPWANs Major Applications

LPWANs can be found in almost all areas of the Business and Industrial sectors, as well as in other sectors such as Communal Living, Service, Science and Education, and others. The foremost application of LPWANs is in the Smart City, one example of such an application being Waste Management and another Smart Lighting, which not only substantially lowers street-lighting costs by varying the intensity of the lighting in accordance with the needs of the environment but also, through fault monitoring, reduces maintenance costs. Connected Vehicles are another example of a specific application; most newer vehicles have networking capability and come equipped with processors and sensors. IoT is able to use these to provide an improved driving experience through such factors as improved road sharing, accident reporting, parking detection etc. Transportation and Logistics applications need the support of factors such as long-range communications, low power, low cost and mobility. The Healthcare area is yet another major market for LPWAN applications; remote health monitoring being one example, etc. At present, the Healthcare sector has seen the widespread adoption of short range wireless technologies such as ZigBee, WiFi, 6LowPAN, together with cellular technologies such as LTE. However, these technologies will not scale due to the increase in the number of sensors giving rise to interference. Attention has therefore now focussed on LPWANs as an alternative communication solution for Healthcare applications due to the high cost of cellular technologies and the limitations of short-range wireless ones.

2.3 LPWANs Unresolved Challenges

Being in the stage of intensive development, LPWANs have a number of problems to solve. Some of them already have solutions but these are not efficient enough, while the solutions of others are still under development and yet other problems have still not been addressed.

Furthermore, there are major challenges of LPWANs which are not as yet satisfactorily resolved, in brief:

Penetration - some applications necessitate the location of the end node inside a building or underground, while the access point may be in another room or outside and above ground. In these applications network range can be considerably reduced by the absorption of walls, soil, etc. Such absorption is frequency-dependent, with lower frequencies generally offering better penetration than higher ones.

Short message handling - some IoT applications need to send substantial amounts of data frequently, while for others it is enough to send only brief messages, often infrequently. The ability of a wireless network to handle short messages efficiently can have a beneficial effect on the network's scalability and the end node's energy consumption. Such handling includes any overhead for the connection setup, interrogation, acknowledgement, and the like.

Bidirectional communications - some end nodes only report data and do not receive commands, so a unidirectional link is adequate for such applications. A bidirectional link, however, provides additional service attributes such as: handshaking with the access point to improve the reliability of data transfers, authentication exchanges for greater security, and sufficient bandwidth for remote software updates and the management of end nodes.

Secure communications - sensitive data needs a secure communications link between end node and access point but, even if the data is not sensitive, security may still be a concern. Without a secure link, an IoT application is more vulnerable to attacks such as spoofing, where a fraudulent end node injects false data into the network or a fraudulent access point hijacks end node data.

Higher level services - a wide-area IoT networking alternative can define any number of levels in the OSI model, from physical and data link layers through to application layers. In some cases the network itself is operated and managed by a service provider that leases users the time to run their network protocols and provides users with cloud services. Other alternatives define the lower layers only and have their access points connected to the Internet or to a private network, leaving the higher OSI layers to the user's choice.

Inter-technology communication - with the rapid growth of LPWAN technologies, the amount of coexisting LPWANs in the same geographical area increases and inter-network coordination becomes an important issue. A big challenge can arise when LPWANs from different vendors need to communicate with each other. Recently, cross-technology-communication (CTC) without additional hardware assistance has been studied for communication across WiFi, ZigBee, and Bluetooth devices. Future research is needed to enable CTC in LPWANs [9].

Increasing Density of LPWAN networks - coexistence challenges arise due to the increase in LPWAN technologies and the expanding deployment of gateways in urban areas. As a result of the random nature of access to the unlicensed bands and of its utilisation, co-existing gateways and a limited number of available channels raise questions about the performance achievable in isolated networks. The devising of coordination mechanisms between gateways from the same or different operators is indispensable if interference and collisions are to be eliminated. The necessary co-existence mechanisms must incorporate coordination and reconfiguration protocols for both gateways and end-devices.

Support for mobility - existing LPWAN technologies are not designed to support mobility, unlike cellular-based technologies, since they rely on wired infrastructure to handle mobility. However, wired infrastructure does not exist in rural environments, especially in remote areas (e.g. farms, oil fields, etc.) where cellular coverage is often weak or absent. The high cost of cellular service is also hindering the adoption of cellular technologies. Generally, support for mobility is quite a challenge for LPWANs and is not well-addressed as yet. Their performance is susceptible to even minor human mobility [10]. Technology-specific features of each LPWAN also make mobility issues such as base station discovery, handoff, and seamless communication quite difficult.

Support for high data rates - the typical data rate supported by LPWAN technologies ranges from 1–100 kbps. Narrowband communication offers long transmission range at the cost of low data rates. In the future, many IoT applications will evolve to include several use cases, such as video streaming, requiring very high data rates [11]. Different approaches to support high data rates in LPWANs should be investigated. Future research directions to enable high data rates include: support of different modulation techniques, borrowing different approaches used in technologies like WiFi, and designing new hardware to support multiple physical layers offering different data rates.

Adaptive power control - future LPWAN optimisation includes the investigation of the use of adaptive power control as a scalability feature. Adaptive power control is used to dynamically adapt the range of the transmissions, based on the distance between sender and receiver. This helps to significantly reduce the interference between stations, especially in densely deployed areas where a short transmission range is sufficient to reach the next hop.

Scheduling mechanisms - more research is needed to investigate the performance of intelligent and automated scheduling mechanisms in the context of long-range IoT networks with only one to a few hops and a variety of traffic patterns. Currently, many existing LPWAN MAC scheduling protocols are based on Carrier-Sense Multiple Access with Collision Avoidance (CSMA-CA) which requires very limited coordination between the access points and stations, and is very bandwidth efficient. However, as the number of the stations attempting to access the channel increases, so does the chance of collisions. This in turn increases the backoff timers and waiting times, causing highly degraded performance. In contrast, Time-Division Multiple Access (TDMA) -based MAC protocols avoid contention altogether. However, as the number of transmitting stations in the network grows, sending slot opportunities decrease, causing ever-growing latency.

Resource sharing and inter-LPWAN coordination - a next set of scalability improvements can be expected through resource sharing and inter-LPWAN coordination. The LPWANs all operate in unlicensed bands, allowing anyone to activate their own LoRaWAN or 802.15.4 network, for example. Considering a single LPWAN technology, this will result in a multitude of co-located networks without any coordination and consequently reduction in scalability due to interference. To share the resources, multiple networks need to cooperate, requiring cross-coordination to reduce interference between co-located single-technology LPWANs. So far, virtualization of wireless networks is focussed on 3GPP LTE and IEEE 802.11 [12]. Additional research is needed to design virtualization solutions and management techniques for LPWAN technology and to investigate the improvement in scalability that can be achieved by applying appropriate coordination mechanisms.

Technology co-existence and interference -as a great many separate networks are deployed in close proximity, mutual interference has to be controlled in order to maintain their operational status. At present, LPWANs are not geared up to handle this impending challenge, which will result in spectrum overcrowding. Existing studies of

LoRa, SigFox, and IQRF demonstrate that coexistence leads to severe performance degradation. The coexistence of four LoRa networks results in the throughput of each reducing to almost one. Current co-existence management for WiFi, existing WSN, Bluetooth does not transfer well to LPWANs as LPWAN devices, due to their large coverage domains, can be subject to an unparalleled number of hidden terminals. Great challenges arise when it comes to enabling the co-existent of different technologies on the same spectrum, due to entities owning so many varying examples. One avenue of research is the detection and identification of other technologies by the use of spectrum information, which can be achieved through the use of an efficient spectrum sensing method or dedicated hardware combined with machine learning techniques to identify those technologies which may be interfering [13].

Interference can be categorised as Inter-network Interference (IrnI) or Intra-network Interference (IanI) when the presence of different networks is being considered. The transmissions in the first category are generated by sensors from two or more different LPWANs. Spectrum sensing, radio environment maps or a spectrum occupancy database are all possible approaches to IrnI mitigation. Interference generated between sensors belonging to the same LPWAN is called IanI, or self-interference. Mitigation of this type of interference can be achieved through collision-recovery and collision-avoidance schemes. There are two known types of IrnI: homogeneous (HoI) and heterogeneous (HeI), the former occurring when two or more networks are utilising the same radio technology and the latter when, for example, different modulation schemes are used [14].

Some approaches to spectrum utilisation monitoring and interference identification used to decrease the negative impact of technology co-existence in LPWANs are discussed in the following section: RF Data Analytics.

An important element for efficient spectrum sharing, resource management and interference management is spectrum monitoring. It is generally agreed that spectrum monitoring should be long-term, ideally permanent; it should also be deployed in major markets and locations, and primarily be focused lower than 3 GHz. The amount of data produced is also agreed to be one of the challenges of spectrum monitoring. In general terms, the measurement and control of technical parameters of radio emissions, collecting spectrum occupancy information, and identification and location of sources of harmful interferences are the problems facing radio frequency (RF) spectrum monitoring. In order to achieve effective dynamic resource allocation, proper approaches to spectrum management are required. These in turn need information about past and present spectrum occupancy, together with information about future spectrum occupancy. An ability to predict variations in spectrum availability is likewise very desirable. Long-term continuous spectrum monitoring provides valuable historical information about spectrum usage, which provides a basis upon which to train an algorithm to predict the future profile of the spectrum. In addition, spectrum holes can be identified and operating frequency bands dynamically assigning to secondary users based on the results of the statistical processing of spectrum availability data.

An infrastructure that can support scalable spectrum data collection, transfer and storage is the first requirement for a spectrum monitoring framework. The end-devices will be required to perform distributive spectrum sensing in order to obtain a detailed overview of the spectrum use over a wide frequency range and to cover the area of interest. The predictive models can be pushed to the end-devices themselves so as to limit the data overhead caused by the vast quantities of I and Q samples generated by the monitoring devices. Electrosense, an initiative using low-cost sensors for large-scale spectrum monitoring in different regions of the world, offering the processed spectrum data as open data was recently proposed [15]. Having access to large datasets is crucial to the evaluation of research advances and to allow wireless communication researchers interested in the field to both acquire a deeper knowledge of spectrum usage and obtain valuable information that can be used to design improved wireless communication systems.

The diversity of technologies operating in different radio bands necessitates the continuous monitoring of multiple frequency bands, causing the volume and velocity of radio spectrum data to be several orders of magnitude higher than the typical data in other wireless communication systems such as WSNs (temperature, humidity reports, etc.). The handling of such a large volume of data, and the extraction of meaningful information across the entire spectrum, requires the design and implementation of a scalable platform to process, analyse and learn from big spectrum. There is therefore a need for efficient data processing and storage systems and algorithms for massive spectrum data analytics in order to extract valuable information from such data and incorporate it in real-time into the spectrum decision and policy process [16].

Inter-cell and cross-technology interference will be among the main communication challenges for 5G. In order to support spectrum decisions and policies in a system of such complexity, 5G networks require to support an architecture capable of flexible spectrum management. Radio-level softwarization will be one of the key enablers for flexible spectrum management, allowing as it does the automation of spectrum data collection, and the flexible control and reconfiguration of cognitive radio elements and parameters. Currently, there has been a growth in interest from academic and Industry circles in the application of Software Defined Networking (SDN) and Network Function Virtualization (NFV) to wireless networks [17]. Such initiatives as SoftAir, Cloud RAN, OpenRadio et al. are however only at the concept or prototype stage. In order to bring flexible spectrum management strategies into being there is still a lot of standardization work to be done. In addition, the spectrum will be monitored by a variety of different types of radio, such as WSNs, RFIDs and cellular phones and for these reasons, privacy must be assured at the spectrum data collection level.

2.4 RF Data Analytics

Thanks to both its expansion of the range of available data sources and its adoption of an approach based not only on quality of experience (QoE) but also on user-centricity, to the optimisation of end-to-end network performance, Data Analytics (DA) brings additional value to optimisation. One result of the widening of the data sources range is that analytics requires more work than standard optimisation, but its compensations include a unified, convergent platform for a multiplicity of optimisation targets. As well as providing traffic steering, network data analytics (NWDA), introduced by 3GPP (3rd Generation Partnership Project) automatically separates 3GPP and non-3GPP access analytics. An industry specification group, Experimental Network Intelligence (ENI), has been created by the European Telecommunications Standards Institute (ETSI) to define a cognitive network management architecture based on artificial intelligence (AI) techniques and context-aware policies. The ENI model assists MNOs to automate the process of network configuration and monitoring.

At present, RF data is regarded as being either time-domain baseband in-phase and quadrature (IQ), or frequency-domain (spectrum). RF data is produced using radio receivers that are able to cover a wide band but which operate in one narrowband at a time. The very high sampling rate requirement of IQ means that is usually appropriate for signals of short duration, this requirement having made the datafication of RF impractical for a long time. Nonetheless this has been something seen as extremely desirable and numerous platforms of generally-increasing capability to produce the so-called "digital IQ" have emerged. As regards spectrum data, the data rate is much lower and normally just an absolute value, obtained via long-term averaging, is retained.

Initially, regarding RF data as just "digital IQ" or spectrum data may appear to be sufficient. But, due to the absence of any information, such as location and centre frequency, about the RF signal this definition is inadequate, especially for RF data analytics. RF data is better defined as time-domain IQ data coupled with all of the metadata such as RF centre frequency, bandwidth, location etc. In this context additional signalling and service traffic must be considered as a major challenge. Likewise, spectrum values paired with metadata may be defined as RF spectrum data. It should be noted that "digital IQ" is not the same as the raw RF signal and thus correct interpretation cannot be achieved without knowledge of parameters such as the RF centre frequency and bandwidth. Such parameters are present, albeit implicitly, in a private cloud, thus leading to them being ignored in the past. When multiple data streams, generated by different types of devices, are present, such metadata cannot continue to be left implied and therefore must be both explicitly defined and paired through association with spectrum data or an IQ stream. Metadata can encompass a large variety of other parameters as well as bandwidth and RF centre frequency. These include antenna beamwidth, polarisation, location, time-stamp, noise, SNR, sampling frequency et al.

DA is made up of three types of data analysis [18]. The first, Descriptive Analysis (DesA), is a combination of Regression, Visualisation and Data Modelling. The purpose of these three steps is to ready the data for the ensuing analysis. Following data collection, a meaningful data representation is prepared, with the final step being the detection of a simple data trend. Spectrum monitoring for operation estimation is one illustration of such a descriptive RF DA service and application. In this instance the object of the monitoring is to commence from information about the systems known to be operational, then to supply spectrum management feedback, that is to say to close the loop by either providing confirmation that devices are operating in accordance with their authorise or showing evidence that they aren't. The architecture and platform under discussion here is able to realise this monitoring service in a more highly efficient way than currently deployed systems are capable of. For quite some time, spectrum usage was constant in terms of time, meaning that one-time measurement campaigns were essentially sufficient. However, the ever-increasing pressure for higher data rates and additional spectrum has resulted in increased complexity of the spectrum environment, meaning that in the future RF devices will be required to share spectrum. There is an increasing need for information on the efficiency of spectrum use, which clearly shows that one-time measurement of spectrum occupancy is no longer adequate. The technology of spectrum monitoring has progressed from one-time through long-term and on to a continuous capability which is no longer conducted using spectrum analysers but instead by specialised platforms.

Following completion of the DesA stage, a Predictive Analysis (PA), comprising Data Mining (DM) and Predictive Modelling (PM), is required. DM, the initial stage, extracts differing patterns from the totality of the collected data. The next step, PM, is aimed at trend recognition and the realization of different prediction techniques. Following completion of the PA the last step of DA is Prescriptive Analysis (PrA), the main objective of which is to use the preceding analysis for decision making and to optimize the entire process.

Two good examples of RF predictive and prescriptive analytics are interference identification and spectrum occupancy forecasting. PA aims to predict the future by developing models based on past data, using Machine Learning (ML) tools. [19] Introduces some of the emergent ML approaches employed as fundamental components of DA, together with an overview of a number of the issues in this field, while [20] presents an illustration of spectrum occupancy forecasting employing ML algorithms on RF data. This particular data was came from long-term spectrum monitoring at a Bulgarian airport traffic control station. It can be seen that the application of proper ML-based DA to the data obtained from long-term spectrum monitoring results in satisfactory forecasts more than 50% of the time.

Yet a further example of PA and PrA can be seen in the measurement results of [21], where the authors demonstrate an approach to the recognition of interference via the large-scale analysis of long term spectrum monitoring data. Unsupervised clustering-based ML analysis is used on long-term spectrum monitoring data to recognise and identify sources of electromagnetic (EM) emissions which adversely impact the performance of a mobile BS. The use of an appropriate RF DA approach is shown to be capable of detecting and identifying a specific type of interference caused by the so-called “ducting” effect in the uplink (UL) channel of a mobile BS.

The major requirements for RF DA is the long-term spectrum monitoring and the implementation of intelligent statistical techniques and ML algorithms. Moreover the RF DA platform must be characterized by high level of control and the ability of intelligent reconfiguration of radio parameters.

3 Conclusion

In this paper, the major applications and unresolved challenges of the most important LPWAN technologies operating in ISM band are presented. In order to enhance the network performance and susceptibility to interference of LPWANs a review of RF Data Analytics is also considered. We conclude that the implementation of the latter is obviously an excellent way to develop new intelligent algorithms for spectrum utilisation analysis and hence for more efficient use of the available spectrum, better interference management and transmission quality management.

In future work, development of models that can accurately describe the different spectrum utilization capabilities in the frequency and time domains aiming to create an energy efficient design of LPWANs is foreseen. Furthermore a research of the actual spectrum utilization in the ISM band across different scenarios and exploring approaches to the possible realization and implementation of mechanisms to provide more effective access to these resources will be considered.

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