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Toward a Versatile IoT Communication Infrastructure

Seyed Mehdi Mousavi
Computer Engineering Department, Islamic Azad University, Science and Research Branch, Tehran, Iran
m.mousavi55@gmail.com

Ahmad Khademzadeh*
Computer Engineering Department, Iran ICT Research Center, Tehran, Iran
zadeh@itrc.ac.ir

Amir Masoud Rahmani
Computer Engineering Department, Islamic Azad University, Science and Research Branch, Tehran, Iran
rahmani74@yahoo.com

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Abstract— **The IoT can lead to fundamental developments in health, education, urbanization, agriculture, industry, and other areas. Regarding the variety of different end-user applications and needs, developing a versatile communication network that can support such diverse and heterogeneous applications is necessary to decrease the implementation costs than developing a dedicated communication network for each application. LoRa is a type of LPWAN networks that is supported by LoRa Alliance and due to long-range communication and low power and reasonable cost, IoT has become the main goal of establishing LoRa. LoRaWAN covers the protocol and architecture of the system on top of the LoRa physical layer. The LoRa physical layer uses proprietary CSS modulation. This modulation operates below the noise level and is resistant to fading, interference, and blocking attacks, and is difficult to decode. LoRa operates in the unlicensed frequency band below 1GHz with different frequencies in different geographical areas. LoRa is much more useful for IoT applications than short-range protocols such as WiFi and Bluetooth, despite limitations in data transfer speeds and QoS. Therefore, in this manuscript, considering the importance and advantages of LoRa, this protocol is introduced and its various network aspect, importance, and application are examined. Then, a solution based on the cognitive radio technique is presented for QoS improvement to utilize the LoRa technology as a kind of versatile communication infrastructure for IoT.**

Keywords: IoT; LoRa; LPWAN; LoRaWAN

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I. INTRODUCTION

With the development of IoT (Internet of Things) technology and its widespread use in various industries, various protocols have been developed for its communication platform. The most important of which are Wi-Fi, ZigBee, Z-wave, LoRa (Long Range), NB-IoT (Narrow Band-IoT), and SigFox.

Wi-Fi, ZigBee, and Z-wave protocols are now commonly used for home devices and rarely used for industrial and urban applications. Wi-Fi protocols have lower infrastructure costs and are more ubiquitous, but they are very expensive and do not allow the use of

* Corresponding Author

batteries in these devices, moreover, they are short-range, and outdoor network coverage is difficult and expensive. ZigBee and Z-wave are in better condition in terms of consumption and can be used without connection to grid or using batteries. But they do not have a suitable range for urban and agricultural applications. In contrast, protocols such as LoRa, NB-IoT, SigFox, which are low power and long-range, are regarded as low power or LPWAN (Low Power Wide Area Network).

LPWAN network technology allows the connection of devices in a wide range, with low power (battery) consumption. LPWAN is the title of a wide range of protocols and technologies that allow sensors and controllers to connect without the use of legacy networks such as WiFi and cellular networks. LPWANs have lower data rates than most conventional wireless networks; But the feature of cheap and cost-effective connection of a large number of end nodes (sensor and operator) has created a great opportunity, especially for IoT solutions. Using this network, sensors, and devices can send information over a distance of several kilometers. Many IoT solutions require sensors to propagate data over a wide range. For example, its applications in smart building complexes, smart cities, smart industry, agriculture, and health care can be mentioned.

As of early 2013, there was no such thing as LPWA, but the need and evidence from the very high potential of LPWA technologies made it one of the most important and evolving aspects of the IoT market. Machina Research Institute, for example, predicts 3.6 billion LPWA connections by 2024. Of course, the issue that needs to be addressed is that LPWAN networks, by creating a wide coverage area, with lower costs and optimal power consumption, are considered as a compliment and not a substitute for cellular networks and short-range technologies. The most important reasons for the emergence of new markets based on this technology are:

1) Low cost: LPWANs can be used to connect a wide range of equipment by selling modems for less than $ 5 and an annual connection cost of less than $ 1 (for some applications). While the use of traditional cellular networks is much more expensive, the cost of LPWANs is also declining year by year.

2) No need for a permanent power supply: Using cellular networks for some IoT applications may seem cost-effective, but it is impossible to use them due to the lack of access to a permanent power supply. Undoubtedly, providing a service that works properly without the need to replace the battery for several years, creates many markets, some of the most important of which can be used in gas and water meters.

3) High-resistance wave propagation: The ability of waves to reach underground depths makes this technology suitable for applications such as connecting underground meters or sewer pipe monitoring sensors.

There are advantages and disadvantages to using any of the LPWAN network solutions in a licensed or unlicensed band. Today, after the introduction of various protocols, the most important networks and LPWAN protocols that have been developed in the market are as follows:

1) SigFox: SigFox network was first introduced in 2009 by the French company, meeting the need for low power networks and low data rates in IoT devices, it developed and introduced its LPWAN protocol. SigFox transmits its data up to 12 bytes in frequency bands without the need for a license and through ultra-narrowband modulation. As a result, the data is sent in a wide range with low speed and high resistance to attenuation and noise. It should be noted that the SigFox protocol and its network are developed exclusively by this company in cooperation with its regional partners.

2) LoRa: LoRa stands for "Long Range", a digital wireless data communication technology for the Internet of Things that enables long-range data transmission (more than 10 km in rural areas) with low power consumption. The LoRa protocol was patented in 2012 by Semtech. LoRa is a proprietary physical layer for LPWA connectivity, and the architecture of its upper layers are defined by the LoRa Alliance under an IP-based transmission method is titled LoRaWAN [2]. The LoRa Association was established in 2015 to support the LoRaWAN protocol as well as to ensure the interoperability of all LoRa products and technologies. This non-profit organization has more than 500 members. According to the LoRaWAN coverage map, there are currently 151 LoRaWAN network operators in 167 countries [3]. LoRa is mainly used in two ways. One is LoRaWAN, which is mostly based in Europe, and the message size managed by this standard is very small about 12 bytes. Another is Symphony Link, which is a product of Link Labs. Symphony Link is a wireless system based on LoRa technology designed to overcome LoRaWAN limitations. The technology is designed as part of the complex LoRa network solutions, mainly in the United States and Canada, for industrial applications.

3) NB-IoT: The NB-IoT network is a long-range low-power technology from the LPWAN network that was developed by the 3GPP standardization organization with the delay and after seeing the widespread need for LPWAN technologies to enable the connection of services and devices through the mobile operator networks. NB-IoT specifically focuses on outdoor coverage, low cost, long battery life, and a high number of connections. Although this technology is a subset of LTE standards, it focuses on the 200 kHz bandwidth. Given that the NB-IoT network is based on mobile cellular networks and in licensed bands, its development model is quite similar to the mobile and operator-based communication networks. Therefore, it is not possible to set up private networks based on this technology, and the development of this network in each region requires the decision of local operators to update mobile sites. The number of devices based on

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this network is much more limited than LoRa and SigFox technologies and their cost is up to 50% more expensive [3].

For example, in Iran, the SigFox network was being implemented for a short time, but due to sanctions, it ended and it is not possible to use it. Because this protocol requires license and equipment, otherwise it cannot be used. NB-IoT is a type of cellular infrastructure provided by some operators and currently, limited coverage has been created in the country, but it is still not desirable, and besides depending on the operators, a permanent subscription fee must be paid to use its infrastructure. But the LoRa protocol can be used as an open-source platform for everyone and can be used independently without dependence on other collections. Most IoT projects in Iran have been implemented on this platform.

In brief, Fig.1 shows the comparison of Sigfox, LoRa, and NB-IoT [3]. According to Fig.1, the LoRa technology relatively passes the most advantages of the IoT factors (battery life, coverage, range, scalability, cost efficiency, and deployment). However, the frequency interference should be mitigated as much as possible, and the QoS (Quality of Service) should also increase to utilize the LoRa technology as a kind of versatile communication infrastructure. If the QoS is improved, it can acceptably support all various low data rate applications of the IoT.

Therefore, in the second section, LoRa ecosystem is introduced, in the third section, LoRa is examined and its modulation, packet format, network architecture, security, transfer parameters are introduced respectively, and in the fourth section, a solution for improving the QoS of LoRa, based on cognitive radio technique, is presented. In the fifth section, the implementation of the proposed versatile infrastructure is examined.

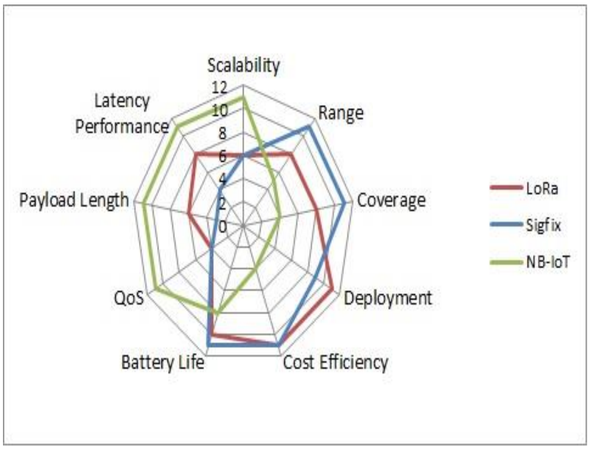

Fig. 1. Top LPWAN Technologies comparison [3]

II. Interpretation of Coding

The LoRa-based IoT ecosystem for the smart city, as shown in Fig.2, consists of four components: sensors (end devices), complementary technologies (gateways), data mining (cloud), and citizen interaction (applications). The generated data of sensors and complementary technologies are delivered to data mining. This data is transformed into models used by citizens and city officials to make appropriate decisions through the data analysis process.

Fig. 2. LoRa-based IoT ecosystem

The first component is sensors, of which three groups of sensors are most commonly used. The first group is sensors that focus on obtaining the value of parameters such as pH and temperature. In agriculture, for example, these sensors allow the identification of suitable conditions for planting and harvesting. In water resources management, the pH sensor allows the evaluation of water quality. The second group includes sensors for measuring gases (ozone, oxygen, air pollutants). The third group includes motion detection sensors. These sensors have a significant impact on the development of applications such as smart parking and security systems for smart homes. The end devices are embedded LoRa sensors and usually include sensors, a LoRa transmitter for transmitting signals through the LoRa platform, and a microcontroller. The sensor imports data from the physical world to the digital world. Continuous monitoring of physical variables such as temperature, humidity, and pH allows users to make decisions about specific aspects of the smart city. Important aspects when using sensors are the two issues of timestamp and sensor identification. The timestamp must be coordinated between the end devices and the gateway to validate the information received by the new and old devices [13]. A local identifier can be used to identify the sensor. This will be useful for knowing which device is sending information.

The second component, complementary technologies, are devices that are used to obtain additional information for specific applications. Complementary technologies are classified into three categories. The first includes locally covered devices that can be detected by a beacon, a small, wireless transmitter that uses Bluetooth technology and low power to send signals to other nearby smart devices. The second case involves personal covered devices that allow individuals to obtain values of physiological parameters such as blood pressure or heart rate. The third case is the wide range of devices that increase the required information resources. For example, the use

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of drones helps to obtain geographical images of the cultivated areas, along with information on pH and temperature, to determine the planting time with high accuracy. LoRa sensors transmit data to the LoRa gateway. LoRa gateways can connect to the Internet via the standard IP protocol and transmit data received from embedded LoRa sensors to a server or cloud. Gateways are always connected to a power supply. The gateways connect to the network server via standard IP connections and act as a transparent bridge, simply converting RF packets to IP packets and vice versa.

LoRa devices work asynchronously and communicate whenever data is ready to be sent. This type of protocol is usually called the Aloha method. In a mesh or synchronous networks (cellular networks), devices are periodically awakened to synchronize with the network and check messages. This synchronization consumes a lot of energy and is the main factor in reducing battery life. In terms of battery life among LPWANs, LoRa has a 3 to 5 times advantage over the others [12].

For a long-distance star network to be stable and viable, the gateway must have a high capacity to receive large amounts of node information. To achieve high capacity in LoRa networks, adaptive multi-channel and multi-modem data rates are used in gateways to receive messages on multiple channels simultaneously. The number of synchronous channels, data rate, length, and how often devices send data is factors that influence network capacity. The emitted LoRa signals are orthogonal to each other. This feature allows the gateway to receive several different data rates at a time on a single channel. If the node has a good link and is near the gateway, there is no reason to use a low data rate and occupy the available range more than it needs. As the data rate increases, the transfer time is reduced and more free space is provided for other nodes. Adaptive data rates also optimize battery life. For the adaptive data rate to work, you need a symmetric uplink and downlink with sufficient capacity in the downlink. These features make LoRa networks more scalable and high capacity. The LoRa network can be implemented with minimal infrastructure adding gateways for the required capacity, increasing data rates, reducing eavesdropping with other gateways, and scaling 6 to 8 times the capacity. Other LPWANs do not have LoRa scalability due to their technical limitations that limit downlink capacity [12].

The third, called data mining, considers the methods used to analyze data obtained from other components and includes machine learning technologies that are used to determine behavioral patterns (categorized normal or abnormal) are used. Data mining gives citizens or city managers more insight into decision-making. In the case of agriculture, for example, identifying behavior that could be related to a potential pest that destroys crops is abnormal behavior. The data generated by IoT devices, sensors, and complementary devices are massive information. Therefore, it is necessary to use the cloud or fog system. Due to sending all data to cloud systems can be expensive, the use of fog computing systems has grown and received more attention in recent years.

Network servers can be cloud-based solutions. Network servers can connect to gateways and route data packets to the application. Network servers can be used for either uplink (sensor to application) or downlink (application to the sensor) connections. The server has a router, broker, and handler that processes data packets sent through the LoRa gateway [12]. Also, Application servers can typically be built on IoT platforms such as AWS IoT or Lambda.

The fourth case focuses on access to data for citizens and city managers. IoT solutions should generate information to improve the decision-making process. Therefore, it is important to deliver relevant information to people by the use of SMS, mobile applications, and web portals. In presenting the information, aspects of the user experience and their accessibility should also be considered [9]. Smart cities include smart metering, smart grids, smart parking, optimized driving and walking paths, energy radiation measurements, nuclear power plant radiation measurements, climate-appropriate street lighting, intelligent waste management, health monitoring, air pollution monitoring, water leak monitoring, forest fire detection, etc., are considered the largest potential customers of LPWAN. Many industries use the LoRa standard for IoT devices, including agriculture (irrigation, water level monitoring, and pest control), water and electricity (electrical equipment control, lighting, energy management scenarios), and construction (building doors and window sensors).

For example, a Chinese bicycle company equips its bicycles with LoRa devices and wireless radio frequency technology to mark the locations of their bicycles. The company currently operates in more than 180 cities in China. An American company also uses a LoRaWAN-based wireless connection to deliver live parking data, making it easier for drivers to find available parking spaces and empty parking spaces in a public and private parking in the street. The ultimate goal is to reduce traffic congestion and carbon emissions are caused by drivers who move repeatedly to find parking.

Iran is one of the countries on the LoRa coverage map and companies in this field are providing services. Also from Iran, the Faculty of Applied Science of Posts and Telecommunications is an academic member of the LoRa international organization and is the only Iranian university that is present in the Alliance. Over the past few years in Iran, some work and activities have been done by universities and the private sector. In 2016, the standards and criteria for the use of LoRa were compiled based on the radio and frequency specifications of Iran by the Radio Regulatory Authority, and in the next phases, the internal sample of the radio was designed and the pilot network was implemented using domestically produced radios. The pilot project has been carried out in Laft and Pahl ports in Hormozgan province using LoRa radio network. In

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this project, the entry and exit of vessels that transport passengers and cargo to the port are automatically registered and this information is linked to the comprehensive marine system software. Before this, the information was entered manually into the system. Due to the traffic that is done quickly, unloading and loading are fast especially during the holidays, the traffic of vessels is high, so it is not possible to register manually. Therefore, in this pilot network, which was installed on five vessels in July 1997, first, two ground stations were designed and installed in Pahl and Laft ports, and five LoRa devices were installed on five vessels. In that WSN network based on LoRa radio, various parameters were measured. It monitors the vessels and the entry, exit and, mooring of the vessels are automatically recorded in the system. This reduces the possibility of error and makes it impossible to manipulate the information.

III. Simulation Results

LoRa is a radio network suitable for IoT solutions and has a better link budget than other similar radio technologies. The link budget is usually expressed in decibels (dB), which is a key factor in determining the range in an environment. In areas often outside the city, a dedicated network port must be established to connect. A gateway or base station can cover hundreds of square kilometers. The signal range is highly dependent on the environment and the obstacles in its path. LoRa technology is well-suited for standalone applications such as smart farming, which does not require mobile communication. LoRa is also very suitable for applications such as stand-alone building which you can create and manage your network. LoRa is also a good option for two-way signals requirement. LoRa devices work well when on the move, which makes it a useful technology for tracking moving objects, such as industries and shipping. LoRa devices also have a longer battery life than NB-IoT devices [5].

A. LoRa modulation:

Many wireless systems use FSK (Frequency Shift Keying) modulation in the physical layer; Because this modulation is very optimal for low power consumption. LoRa is in the physical layer and uses CSS (Chirp Spread Spectrum) modulation of the DSSS families, which can be both low power and long-range like FSK. CSS modulation is an old modulation method that was developed in 1940 and was originally used for military communication [6]

CSS proprietary modulation has been used in the military and aerospace industries for many years due to its long-range and high interference resistance, but LoRa is the first low-cost implementation for commercial use of this modulation. CSS modulation is a digital communication spread spectrum that uses broadband linear frequency modulated chirp pulses to encode information. The word "chirp" stands for "Compulsive High-Intensity Radar Pulse", which defines the increase and decrease of signal frequency over time during the modulation process. Chirp is a sinusoidal signal whose frequency increases or decreases over time.

As shown in Figure 3, the "high chirp" moves upward in frequency and the "low chirp" moves below the central frequency. This modulation transfers a single bit of information into another set of bits and extends them across the spectrum. This modulation operates below the noise level, and because the transmitted signal is similar to the noise signal, it is resistant to multipath fading and Doppler effect, interference, and blocking attacks, and is difficult to decode. The receiver can decode even a weak signal below the noise level [5].

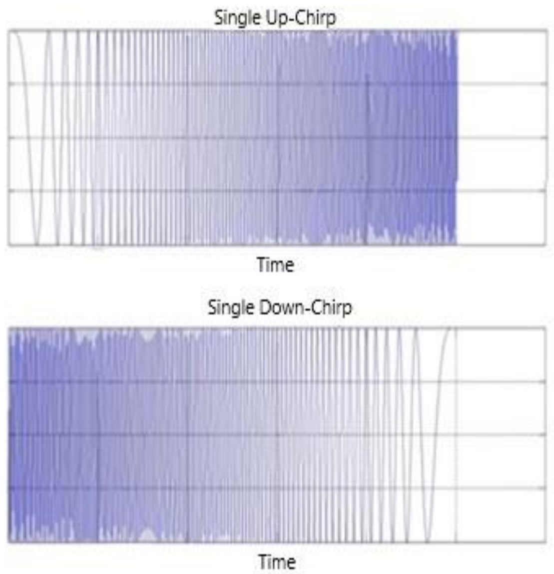

Fig. 3. High Chirp and Low Chirp signals [8]

B. LoRa packet format:

LoRa data packets size can be up to 256 bytes. This LoRa feature makes it a low-speed data transfer technology, which is acceptable for sensor networks. Data frames in IoT applications can have different lengths, depending on various factors such as the type of data, the number of packets, the application design, and the required delays. IoT solutions include 8-byte short packets or 128-byte long packets. For example, a light monitoring solution uses 10-byte frames for communication between light bulbs, 5-byte frames for agricultural applications (fruit planting monitoring), and 12-byte long frames for cyclist tracking.

For health applications, 93 bytes data frames are used to send health information such as blood pressure and pulse pressure. Regarding water quality, salinity and temperature information is sent in the form of 17-byte data. LoRa variable data frame length provides more flexibility in developing IoT applications for smart city applications. Data frame length that includes payload and header can affect the transfer time and energy consumption. Technical factors such as BW (Band Width), SF (Spreading Factor) and, throughput can affect data length [9]. Figure 4, shows the packet format used in LoRa. LoRa offers a maximum packet

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size of 256 bytes. The format of the LoRa packet is as follows:

1. Preamble field: Used for synchronization purposes.
   The receiver is synchronized with the input data stream.
2. Header: Depends on the choice of two available operating
   modes. The first is the default explicit operation mode, which specifies the number of bytes in the header, forward error correction code rate (FEC), payload length, and cyclic redundancy check (CRC), presence in the frame. The second mode is the implicit operation mode, which specifies the payload encoding rate in a fixed frame. In this case, the frame does not contain a header, which reduces transmission time. The length of the header with its CRC is 4 bytes. The first byte of the header section specifies the length of the frame.
3. Payload field: The maximum payload varies from 2 to 255
   bytes, which includes the following:

MAC header: defines the frame type (data or authentication),

the protocol version and its direction (uplink or downlink)

MAC payload: contains real data.

MIC: Used as a digital signature for payload.

CRC: Optional to protect against payload errors (2 bytes).

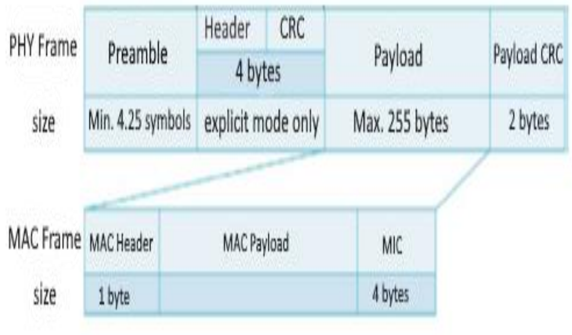

Fig. 4. LoRa frame format [8]

C. *LoRa transfer parameters:*

Important transmission parameters considered in LoRa are central carrier frequency, bandwidth, data rate, encoding rate, and spreading factor. LoRa modulation is directly related to data rate, expansion factor and, bandwidth. LoRa uses the Adaptive Data Rate or ADR algorithm to estimate the parameters of the coding rate and the coefficient of spreading a given channel. The choice of these parameters should be following the technical and operational requirements of IoT solutions. In general, LoRa is much needed for the IoT system, despite its disadvantages such as limited transmission speed and payload size compared to short-range protocols.

LoRa central frequency depends on the geographic area and is 915 MHz in the United States (also available in the range of 902 MHz to 928 MHz), 868 MHz in Europe (also 433 MHz), 470 MHz in China, 923 MHz in Japan, 915 MHz in Australia (also frequencies between 915 MHz and 928 MHz) and 433 MHz in the west of Asia. LoRa uses three bandwidths: 125 kHz, 250 kHz, and 500 kHz [11]. All communication packets between end-devices and gateways also have a variable data rate (DR) setting. DR selection allows dynamic interaction between communication range and message duration. Also, due to the spread spectrum technology, communications with different DRs, do not interfere with each other. According to Equation (1), the data rate is a function of the spreading factor, and bandwidth (bits/sec):

$$DR = SF * \frac{1}{\frac{2^{SF}}{BW}} \; bits/sec \tag{1}$$

LoRa uses several orthogonal spreading factors between 7 and 12. SF creates a trade-off between data rate and range. In this way, by choosing a higher spreading factor, the range can be increased, but the data rate decreases, and vice versa. Each symbol is expanded by a spreading code of 2^{SF}. In the transmitter, the spreading code is divided into subcodes with a length of $2^{SF}/_{SF}$, then each bit of the symbol is expanded using the subcodes shown in Fig.5. Thus, a symbol for expansion takes up 2^{SF} parts. This code is also known as the extender code. Replacing a symbol for multiple pieces of information means that the spread factor has a direct effect on the effective data rate. The relationship between data rate and SF for the three bandwidths is shown in Fig.6. The receiver multiplies the input coded data in the received bits to reconstruct it [8].

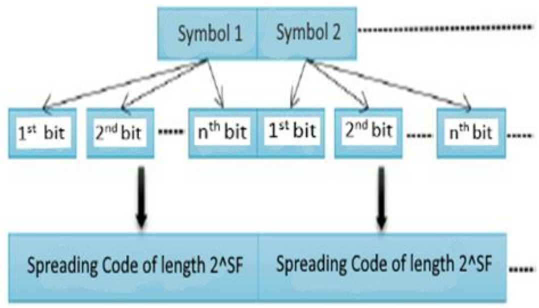

Fig. 5. LoRa spreading model

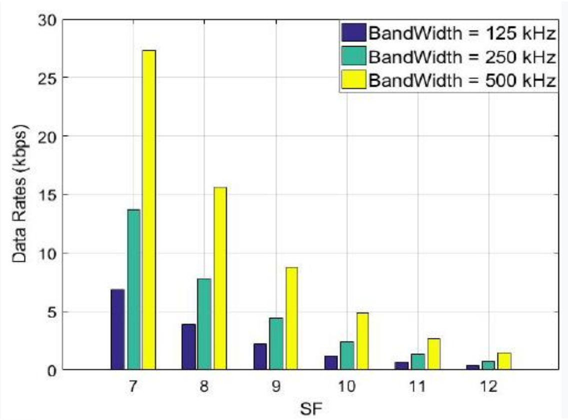

Fig. 6. LoRa data rates with different SF and bandwidth

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Forward error correction (FEC) methods are used in LoRa to increase the sensitivity of the receiver. The code rate defines the FEC value. LoRa defines the CR value between 0 and 4. Where CR = 0 means no FEC. The redundant bits enable the recipient to detect and often correct errors in the message but reduce the effective data rate. The data rate with each CR value in LoRa is shown in Fig.7. As CR increases, the data rate in each bandwidth spectrum decreases [8].

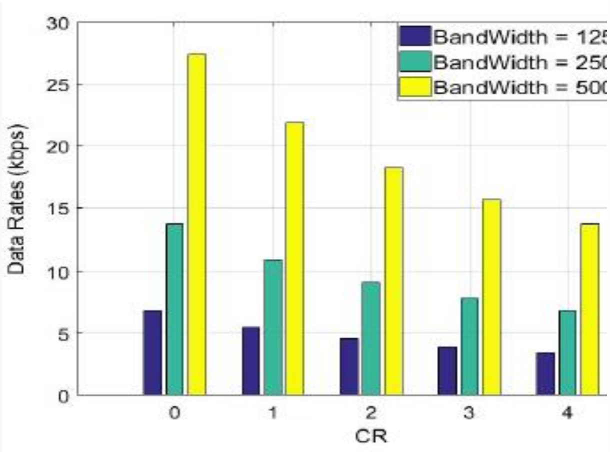

Fig. 7. LoRa data rate with different code rates and bandwidth values (SF = 7)

In LoRa technology, if the selected SF is high, its throughput and payload are low. For example, for 125 kHz bandwidth, at 868 MHz, if you choose SF 7, the throughput is 5470 bits per second and the payload is 230 bytes. If the SF is selected 12, the throughput is reduced to 250 bits per second and the payload to 59 bytes. The choice of bandwidth also affects the payload length. For example, for the same frequency of 915 MHz and the same SF 7, if the selected bandwidth is 500 kHz, the throughput is 21,900 bits per second and the payload rate is 230 bytes. In contrast, if the selected bandwidth is 125 kHz, the throughput is reduced to 5470 bits per second and the payload is increased to 250 bytes [9].

D. LoRa network architecture:

LoRaWAN defines the communication protocol and system architecture for the network, while the LoRa physical layer enables long-range communication. LoRaWAN is a Media Access Control Layer (MAC) protocol on top of the LoRa physical layer developed and patented by Semtech. For this reason, the terms LoRa and LoRaWAN cannot be used interchangeably. Fig.8 shows the LoRaWAN protocol architecture [11].

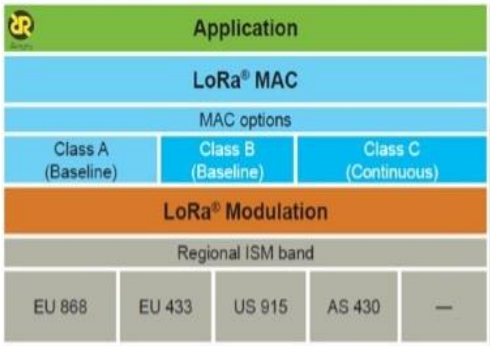

Fig. 8. LoRaWAN architecture [11]

Many networks use mesh topology in their architecture. In mesh networks, each end device also transmits information to others to increase communication range and cell size. In this topology, increasing range increases complexity reduces network capacity and reduces battery life because each end device receives and transmits information to other devices that are not even related to them. LoRaWAN uses a long-range star architecture that saves battery life. The connection between the sensor devices and the base stations is established via the wireless channel using the LoRa physical layer, while the connection between the gateways and the central server is established via the IP network. In LoRaWAN networks, nodes do not connect with a single gateway, but the data transmitted from the end device is usually received by multiple gateways. Each gateway will transmit data received from the end devices through its backhaul (mobile network, ethernet, satellite, or Wi-Fi) to the server [12]. The end devices (sensors and applications) communicate with one or more gateways via LoRa single-hop communications. Intelligence and complexity will be left to the network server that manages the network, such as filtering duplicate data, performing security checks, scheduling acknowledgments between gateways, and applying adaptive data rates. Because the network can choose the best quality of information among the information transmitted by different gateways, there is no need for hand-off or handover [12].

E. LoRa security

Security is very important for any LPWAN. LoRaWAN has two layers of security: one for the network and one for the application. Network security ensures end device authentication on the network while the application security layer ensures that the operator does not have access to user information. AES encryption is used with a key exchange using the IEEE EUI64. Accordingly, the LoRaWAN specification defines two layers of encryption:

A unique 128-bit network key (NwkSkey) is shared between the endpoints and the network server.

A unique 128-bit functional key (AppSKey) is eventually shared by the app.

LoRaWAN data is encrypted twice. The sensor data is encrypted by the device and then re-encrypted by the LoRaWAN protocol. Then will it be sent to the

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LoRa gateway. The gateway sends data to a network server over a conventional IP network. The network server has network keys (NwkSkey) and decrypts LoRaWAN data. It then transfers the data using the app key (AppSKey) to the application server, which transmits the sensor data decoding. Because the LoRa gateway operates at an unlicensed frequency, it can receive data from all sensors in the vicinity. But LoRa gateways may not be able to decrypt all sensor data. It is important to note that the LoRaWAN communication protocol adds encryption. LoRa transmission is in itself a simple radio wave transmission and is not encrypted. LoRaWAN devices have two ways to connect to the network. The first is OTAA (Over-the-Air Activation). The device and network exchange a 128-bit AppKey. AppKey is used to generate a message integration code (MIC) when the device sends a request to join. Then, the server checks the MIC with AppKey. If the code is valid, the server generates two new 128-bit keys, the app session key (AppSkey) and the network session key (NwkSkey). These keys are sent to the device using AppKey as the encryption key (using AES-128). When receiving the keys, the device decrypts and installs the two keys.

The second way is to join the ABP (Activation by Personalization) network. In this case, the device keys are entered by the user, which can cause security problems.

IV. IMPROVING THE QOS OF LORA BASED ON COGNITIVE RADIO TECHNIQUE

LoRa technology provides low-cost communications and easy deployment by using the unlicensed frequency spectrum. However, due to the possibility of frequency interference with other technologies that use the unlicensed frequency spectrum, QoS will be lower than technologies that use the licensed frequency spectrum.

Usually, the frequency spectrum cost is very high. The ISM frequency bands (unlicensed spectrum) are free, whereas the communication quality is lower due to the possibility of frequency interference. LoRa often employs 800–900 MHz unlicensed spectrum. Many licensed spectra are rarely used or not used at all. Thus, if LoRa devices can utilize unused licensed spectra, the interference will decrease and the QoS and efficiency of communications will increase. For instance, the 800 MHz frequency band is exclusive to analog TV signals in Iran; thus, it is practically useless. However, nobody wants to abandon this frequency band. There can be a useful solution for using this band for either TV or telecommunication purposes simultaneously. The cognitive radio technique can manage spectrum access for the use of vacant licensed spectrum channels. However, the licensed users benefit from a higher priority; hence, the channels occupied by end-devices should be released if the licensed users need to employ the channels.

Cognitive radio is the intelligent technology for dynamically allocating the frequency spectrum that makes optimal use of the available frequency spectrum by changing the radio parameters. This technology allows unlicensed users (secondary users) in addition to working with licensed users (primary users). Secondary users can use the frequency band at times when it is not occupied by primary users. Cognitive radio is a smart radio that can detect spectral holes where frequency bands are empty of licensed users. In other words, spectral holes are frequency bands that are originally allocated to the primary user, but at a specific time and geographical area, the licensed user does not use this band. Then, cognitive radio allocates this vacant band to secondary users. Obviously, despite the ability to identify existing spectral holes for sending data, the use of cognitive radio makes the utilization of the frequency spectrum more efficient. Cognitive radio should use the existing frequency band in such a way it does not interfere with the primary users who have a higher priority. In other words, primary users should not feel the presence of secondary users in their frequency band. There are different approaches to measuring the electromagnetic environment to check for the presence or absence of user signals. The most important and cheapest technique is to use the energy detection (ED) method. Spectrum management is an effective way to prevent interference between primary and secondary users. When some parts of the licensed spectrum are used and primary users arrive, the spectrum manager detects PUs arrival by ED method and vacates the licensed spectrum. In other words, If the primary system requests its frequency spectrum while the secondary user is using it, the spectrum manager is required to release the spectrum and to continue the secondary user`s transmission by another frequency band.

The proposed solution that can improve the QoS of LoRa with cognitive radio technique, is presented in Fig.9.

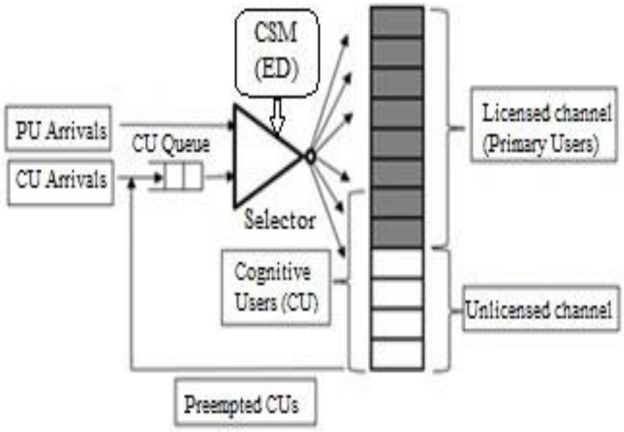

Fig. 9. Proposed cognitive spectrum management model

In this model, two types of heterogeneous radio systems employ the frequency band. The first type works in the licensed frequency band as primary users (PUs) same as cellular network users. In contrast, the second type works in the unlicensed band as secondary users or cognitive users (CUs) same as LoRa users. The

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PU frequency channels are often unused; hence, the CUs can use some parts of the licensed channels in this model as long as they do not interfere with the PUs. The cognitive spectrum manager (CSM) module manages the spectrum. The CSM is placed inside the access gateways for any cells and uses the ED method for measuring the electromagnetic environment to check for the presence or absence of primary user signal in the model. The CSM is an effective way to avoid interference between primary and secondary users. PU always has priority for the use of the shared spectrum. If PU arrives at the system, the CSM immediately detects that and preempts the channels used by the CUs if necessary. In other words, when PU arrives at the system to employ a channel used by CUs, the cognitive spectrum manager detects that and immediately releases a licensed channel to transfer CUs to another channel. If there are no vacant channels, CUs will stay in the queue. The mechanism of this queue is first come first served (FCFS). The number of channels shared by PUs must be selected at a suitable ratio because if PU preempts the shared channels, the QoS will severely decline for CUs.

For performance analysis of this model, in the steady-state, considering the LoRa users, arrival process model follows the Poisson distribution, whereas the arrival rate is λ . Moreover, the service time rate is μ as Exponential distribution, whereas the traffic load is ρ . The spectrum occupation process model for the CUs is defined as a continuous Markov chain [23]. In other words, the LoRa sensor nodes are assumed to be turned on and off in a random style that is independent of other IoT devices. The licensed spectrum is also assumed to have c channels, some of which can be assigned to CUs. In total, there are m channels for unlicensed users. The PU has the priority to use licensed spectra and preempt bands occupied by CUs. The time between two arrivals and the service time is Exponential distribution; hence, the arrival of CUs can be simulated as an exponential queue model ($M/M/m$). In this exponential queue model, there are m servers or channels for the CUs, whereas there are no constraints on the queue capacity. To improve the QoS in the proposed cognitive spectrum management model, it is necessary to reduce the probability of PUs blocking, reduce the meantime of CUs staying on the queue (W_q), and decrease the service time (μ) . Also, the probability of all occupied PUs channels (π_c) should decrease to reduce the probability of system blocking. Therefore, to evaluate the QoS of the proposed model, a service quality factor (SQF) can be defined as follow (w_f is a weight factor):

$$SQF = \frac{w_f(1-\pi_c)}{W_q\ \mu} \qquad (2)$$

In a sample network with the parameters presented in Table 1, the SQF value for two different LoRa modes was examined and analyzed using the Mathcad. In the first mode, the performance of the LoRa protocol was analyzed without using the proposed model and in the second mode, the performance of the LoRa protocol was analyzed using the proposed method (LoRa with CSM). As shown in Fig.10, LoRa user quality of service will improve by the proposed method.

TABLE I. NUMERICAL ANALYSIS PARAMETERS

Parameter	Value	Description
λ	0.01-0.09	User arrival rate
μ	0.2	Service time
m	3,5	Number of unlicensed channels
SQF	-	Service Quality Factor
Wq	-	Mean waiting time in the queue

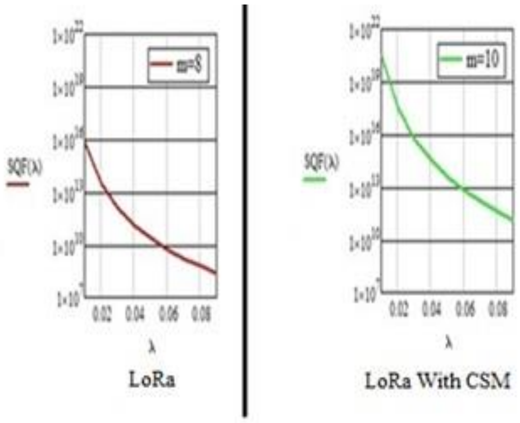

Fig. 10. LoRa vs. LoRa with CSM (SQF)

V. PROPOSED LORA VERSATILE INFRASTRUCTURE IMPLEMENTATION

Fig. 11 shows an implementation for the proposed versatile IoT communication infrastructure by LoRa protocol.

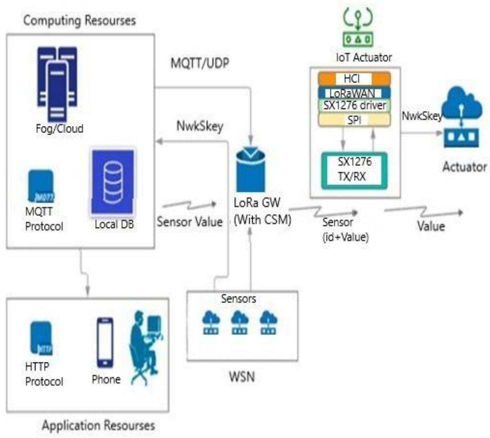

Fig. 11. Proposed IoT versatile infrastructure

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In this implementation, the sensors use a local identifier to identify and the information collected by the sensors is sent at specified intervals. The LoRa gateway (with CSM) receives the local ID sensor and sensed values, which are routed to the Fog or Cloud computing infrastructure. The values sent by the sensors are stored in the local database for data analysis. Then control messages are sent to the operators [14]. A lightweight protocol is used to easily extend and optimize communications. The most popular of these protocols is the Message Queuing Telemetry Transport protocol (MQTT) and the Constrained Application Protocol (COAP), both of which are designed for resource-limited devices. MQTT supports multiple end devices that communicate with a central interface. Interface information can be accessed in real-time by personal computers or mobile devices [15]. Once the LoRa gateway detects the sync word, it retransmits the received packet from the end devices via the local MQTT via ESP8266. The ESP8266 is a Wi-Fi module used to provide an Internet interface for the LoRa gateway. The connection between the LoRa gateway and the ESP8266 is via the SPI connection. MQTT is also used for the web interface. MQTT is known as the Machine-to-Machine (M2M) communication protocol on the Internet of Things.

The amount of energy that sensors use varies depending on the type. Although low energy consumption (voltage range between 2.2 to 5 volts and amps less than 1 mA) needs to be considered in the design of IoT solutions, as the end nodes depend on low-consumption lithium batteries.

LoRa projects typically use DTH XX series sensors due to their ease of configuration, low cost, and good accuracy. In addition, the availability of libraries for these types of sensors in different programming languages reduces the time and increases efficiency for developing and implementing LoRa-based IoT solutions. The DTH11 and DTH22 sensors are digital sensors. DTH22 can measure temperature in the range of 40 to 80 ° C with an accuracy of 0.5 ° C and humidity in the range of 0% to 100% RH (relative humidity) with an accuracy of 2% RH. DTH11 operates in the temperature measurement range up to 50 ° C with an accuracy of 2.0 ° C and in the humidity range from 20% to 90% with an accuracy of 4% RH. DTH11 and DTH22 sensors can transmit bits to nodes in LoRa ecosystems. The complete data transmission of DTH11 and DTH 22 consists of 40 bits (5 bytes) throughout 4 milliseconds. Two bytes for temperature measurement, two bytes for humidity measurement and, 1 byte for error rate control. DTH11 and DTH 22 are not high-precision sensors, but their accuracy is acceptable. DTH11 can be used in experiments or home projects, while DTH22 works with moderate accuracy and can be used for city-wide monitoring [9]. The sensors may be connected to a LoRa transmitter chip or a unit integrated with the LoRa transmitter chip. Various modules such as ESP8266, SX1272, and SX 1276 are used to communicate between devices. The ESP8266 is an integrated low-power chip with 17 public input ports (GPIO) that allows the integration of LoRa receiver modules. The operating voltage of ESP8266 is in the average range between 3 to 3.6 volts and the operating current is 80 mA. The operating temperature range is from 40 to 125 ° C. The main communication gateways are used by ESP8266 such as SPI, I2C, UART, and the module supports protocols such as TCP, UDP, HTTP, FTP. The ESP8266 has three operating modes:

- Active mode: Consumes about 170 mA at full capacity.
- Sleep Mode: Sync Time (RTC) is enabled for syncing. In this case, the ESP8266 maintains the data connection and there is no need to reconnect. In this case, the chip consumes between 0.6 mA and 1 mA.
- Deep sleep: RTC is not operational. Unsaved data is lost.

The SX1272 provides a wide range of communication with a very high range and high interference immunity. The operating frequency is 860-1000 MHz. Other features include 157 dB as maximum link budget, programmable bit rate up to 300 kbps, low sensitivity up to -137 dBm, FSK, GFSK, MSK, GMSK, LoRa, and OOK modulation types. SX1276 receivers offer very long-range spread spectrum communication and very high interference immunity. The operating frequency is between 137 to 1020 MHz and the maximum link budget is 168 dB. Its programmable bit rate is up to 300 kbps, sensitivity up to -148 dBm and the types of modulation used are the same as SX1272 [16].

Smart city applications can be developed using low-cost hardware such as the Arduino and Raspberry pi, which maintains a high level of performance and accuracy. Fig.12 shows some of the Arduino models used in the LoRa implementation, such as the Arduino Nano, Arduino Mega, Arduino Uno, and Raspberry pi Model B. Arduino hardware allows the connection of different classes of sensors and receiver communication modules. The main difference between Arduino models is the number of GPIOs and their cost. These aspects should be considered in designing IoT solutions [18]. It is possible to program microcontrollers in Micro Python or Micro JavaScript. This allows developers to use sensor data such as accelerometers, temperatures, etc., and implement specific uses. Crash detection algorithms may be run by microcontroller programming based on accelerometer inputs and other sensors.

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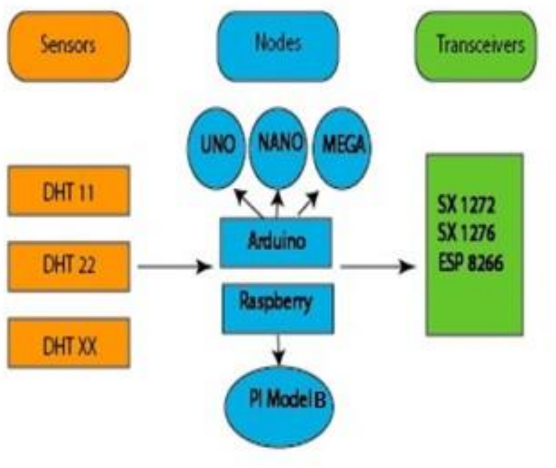

Fig. 12. Sensors, nodes, and transceivers for LoRa implementation

LoRa end devices (sensors) are usually low power and have batteries and are classified into three classes for optimization in various applications and different MAC protocols are designed for these three classes of devices. The difference between these classes is communication delays, downlink, and battery life. In applications where an operator is to be controlled, the downlink communication delay is very important. Class A and Class B sensors have batteries that can typically last 2 to 5 years. LoRa sensors can transmit signals from distances of 1 km to 10 km. The following are also important for classes:

Class A two-way end devices: In this class, two-way communication is established, which is followed by two downlink receiving windows after each uplink transfer. Class A is the most energy-efficient system for applications that have a downlink connection shortly after the uplink reaches the device. Downlink connections that occur from the server at other times will have to wait for an uplink connection to be established by the device.

Class B double-sided end devices with programmed receiving slots: In addition to Class A where random receiving windows are created, Class B receiving windows open at specified times. For the end device to be able to open the receiving window at the specified time, it is synchronized with the gateway through the signal it receives from the gateway. This way the server knows when the device is listening.

Class C double-sided end devices with receiving slots: Class C devices always have their receiving window open except when sending [16].

Also, as shown in Fig.12, The cognitive spectrum manager (CSM) module in the LoRa gateway manages the spectrum. It places inside the LoRa gateway for any cells. CSM uses the ED method for measuring the electromagnetic environment. Sensors in any class can use a licensed channel that is defined, the same as unlicensed channel. If licensed users arrive and want to use the channel, CSM releases the channel for them.

VI. Conclusion

The LoRa protocol introduced and its various network aspect, importance, and application examined. Among the various protocols, LoRa wireless products are the best solution to reduce costs, long-range, low power consumption, and thus increase battery life and improve network capacity for IoT pervasive applications in various industries. In general, LoRa is a much-needed IoT system with many advantages, as well as disadvantages such as limited transmission speed and QoS compared to short-range protocols. Despite that, the proposed cognitive radio technique improves QoS of LoRa by using licensed channels same as the unlicensed channels with licensed user priority. Thus, in all respects, LoRa with cognitive spectrum manager can be introduced as the best platform for implementing IoT projects as a versatile communication infrastructure.

References

[1] Navarro-Ortiz, J., Sendra, S., Ameigeiras, P., & Lopez-Soler, J. M. (2018). Integration of LoRaWAN and 4G/5G for the Industrial Internet of Things. *IEEE Communications Magazine*, *56*(2), 60-67. https://doi.org/10.1109/MCOM.2018.1700625.

[2] P. K. a. M. S. Usman Raza, "Low Power Wide Area Networks: An Overview," IEEE, Volume 19, Number 2, pp. 855 - 873, 2017.

[3] Mekki, K., Bajic, E., Chaxel, F., & Meyer, F. (2019). A comparative study of LPWAN technologies for large-scale IoT deployment. *ICT express*, *5*(1), 1-7. https://doi.org/10.1016/j.icte.2017.12.005.

[4] Rubio-Aparicio, J., Cerdan-Cartagena, F., Suardiaz-Muro, J., & Ybarra-Moreno, J. (2019). Design and implementation of a mixed IoT LPWAN network architecture. *Sensors*, *19*(3), 675. https://doi.org/10.3390/s19030675.

[5] Augustin, A., Yi, J., Clausen, T., & Townsley, W. M. (2016). A study of LoRa: Long range & low power networks for the internet of things. *Sensors*, *16*(9), 1466. https://doi.org/10.3390/s16091466.

[6] Boulogeorgos, A. A. A., Diamantoulakis, P. D., & Karagiannidis, G. K. (2016). Low power wide area networks (lpwans) for internet of things (iot) applications: Research challenges and future trends. *arXiv preprint arXiv:1611.07449*.

[7] Qadir, Q. M., Rashid, T. A., Al-Salihi, N. K., Ismael, B., Kist, A. A., & Zhang, Z. (2018). Low power wide area networks: A survey of enabling technologies, applications and interoperability needs. *IEEE Access*, *6*, 77454-77473. https://doi.org/10.1109/ACCESS.2018.2883151.

[8] "A Study of LoRa Low Power and Wide Area Network Technology," in 3 rd International Conference on Advanced Technologies for Signal and Image Processing ATSIP'2017, Fez, Morroco, 2017.

[9] R. O. Andrade and S. G. Yoo, "A Comprehensive Study of the Use of LoRa in the Development of Smart Cities," Applied Sciences, Volume 9, Number 22, p. 4753. 2019.

[10] Onumanyi, A. J., Abu-Mahfouz, A. M., & Hancke, G. P. (2020). Low power wide area network, cognitive radio and the Internet of Things: Potentials for integration. *Sensors*, *20*(23), 6837. https://doi.org/10.3390/s20236837.

[11] A. Augustin, J. Yi, T. Clausen and W. Townsley, "A Study of LoRa: Long Range & Low Power Networks for the Internet of Things," Sensors 2016-MDPI journals2016.

[12] Bahashwan, A. A., Anbar, M., Abdullah, N., Al-Hadhrami, T., & Hanshi, S. M. (2021). Review on Common IoT

[Downloaded from journal.itrc.ac.ir on 2024-04-25]

[DOI: 10.52547/itrc.14.1.25]

Communication Technologies for Both Long-Range Network (LPWAN) and Short-Range Network. In *Advances on Smart and Soft Computing* (pp. 341-353). Springer, Singapore. https://doi.org/10.1007/978-981-15-6048-4_30

[13]] S. Kim, M. Lee and C. Shin, "IoT-Based Strawberry Disease Prediction System for Smart Farming," Sensors,Volume 18, Number 11, pp. 40-51, Nov. 2018.

[14] J. Paredes-Parra, A. García-Sánchez, A. Mateo-Aroca and Molina-Garcia, "An Alternative Internet-of-Things Solution Based on LoRa for PV Power Plants: Data Monitoring and Management," Energies, Volume 12, Number 5, p. 881, Mar. 2019.

[15] U. Dos Santos, G. Pessin, C. da Costa, and R. A. da Rosa Righi, "A Proactive Internet of Things Model to Anticipate Problems and Improve Production in Agricultural Crops," in Computers and Electronics in Agriculture; Applied Computing Graduate Program, Unisinos, Brazil, 2018.

[16] A. Alsohaily, E. Sousa, AJ Tenenbaum and I. Maljevic, "LoRaWAN radio interface analysis for North American frequency band operation," in 2017 IEEE 28th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC) Montreal, QC, Canada, 8-13 Oct. 2017.

[17] Chen, M., Miao, Y., Jian, X., Wang, X., & Humar, I. (2018). Cognitive-LPWAN: Towards intelligent wireless services in hybrid low power wide area networks. *IEEE Transactions on Green Communications and Networking*, *3*(2), 409-417. https://doi.org/10.1109/TGCN.2018.2873783.

[18] I. Rodriguez, M. Lauridsen, G. Vasluianu, A. Poulsen and P. T. g. s. c. l. l. Mogensen, "Amulti-arena lora-based testbed," In Proceedings of the International Symposium on Wireless Communication, Lisbon, Portugal, August 2018.

[19] Saifullah, A., Rahman, M., Ismail, D., Lu, C., Liu, J., & Chandra, R. (2018). Low-power wide-area network over white spaces. *IEEE/ACM Transactions on Networking*, *26*(4), 1893-1906. https://doi.org/10.1109/TNET.2018.2856197.

[20] Dongare, A., Hesling, C., Bhatia, K., Balanuta, A., Pereira, R. L., Iannucci, B., & Rowe, A. (2017, March). OpenChirp: A low-power wide-area networking architecture. In *2017 IEEE International Conference on Pervasive Computing and Communications Workshops (PerCom Workshops)* (pp. 569-574). IEEE. https://doi.org/10.1109/PERCOMW.2017.7917625.

[21] Chen, M., Miao, Y., Jian, X., Wang, X., & Humar, I. (2018). Cognitive-LPWAN: Towards intelligent wireless services in hybrid low power wide area networks. *IEEE Transactions on Green Communications and Networking*, *3*(2), 409-417. https://doi.org/10.1109/TGCN.2018.2873783.

[22] Sallum, E., Pereira, N., Alves, M., & Santos, M. (2020). Improving quality-of-service in LoRa low-power wide-area networks through optimized radio resource management. *Journal of Sensor and Actuator Networks*, *9*(1), 10. https://doi.org/10.3390/jsan9010010

[23] Moon, B. (2017). Dynamic spectrum access for internet of things service in cognitive radio-enabled LPWANs. *Sensors*, *17*(12), 2818. https://doi.org/10.3390/s17122818.

[24] Mikhaylov, K., Stusek, M., Masek, P., Petrov, V., Petajajarvi, J., Andreev, S., ... & Koucheryavy, Y. (2018, May). Multi-rat lpwan in smart cities: Trial of lorawan and nb-iot integration. In *2018 IEEE International Conference on Communications (ICC)* (pp. 1-6). IEEE. https://doi.org/10.1109/ICC.2018.8422979.

[25] Onumanyi, A. J., Abu-Mahfouz, A. M., & Hancke, G. P. (2019). Cognitive radio in low power wide area network for IoT applications: Recent approaches, benefits and challenges. *IEEE Transactions on Industrial Informatics*, *16*(12), 7489-7498. https://doi.org/10.1109/TII.2019.2956507.

[26] Al-Turjman, F. (2017). *Cognitive sensors and IoT: architecture, deployment, and data delivery*. CRC Press.

[27] Haxhibeqiri, J., De Poorter, E., Moerman, I., & Hoebeke, J. (2018). A survey of LoRaWAN for IoT: From technology to application. *Sensors*, *18*(11), 3995. https://doi.org/10.3390/s18113995.

[28] Petroni, A., Cuomo, F., Schepis, L., Biagi, M., Listanti, M., & Scarano, G. (2018). Adaptive data synchronization algorithm for iot-oriented low-power wide-area networks. *Sensors*, *18*(11), 4053. https://doi.org/10.3390/s18114053.

[29] Djedouboum, A. C., Abba Ari, A. A., Gueroui, A. M., Mohamadou, A., & Aliouat, Z. (2018). Big data collection in large-scale wireless sensor networks. *Sensors*, *18*(12), 4474. https://doi.org/10.3390/s18124474.

[30] Al-Fagih, A. E., Al-Turjman, F. M., Alsalih, W. M., & Hassanein, H. S. (2013). A priced public sensing framework for heterogeneous IoT architectures. *IEEE Transactions on Emerging Topics in Computing*, *1*(1), 133-147. https://doi.org/10.1109/TETC.2013.2278698.

[31] Fantacci, R., Pecorella, T., Viti, R., & Carlini, C. (2014). A network architecture solution for efficient IOT WSN backhauling: challenges and opportunities. *IEEE Wireless Communications*, *21*(4), 113-119. https://doi.org/10.1109/MWC.2014.6882303.

[32] Saari, M., bin Baharudin, A. M., Sillberg, P., Hyrynsalmi, S., & Yan, W. (2018, May). LoRa—A survey of recent research trends. In *2018 41st International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)* (pp. 0872-0877). IEEE. https://doi.org/10.23919/MIPRO.2018.8400161.

[33] Bonnefoi, R., Moy, C., & Palicot, J. (2018). Improvement of the LPWAN AMI backhaul's latency thanks to reinforcement learning algorithms. *EURASIP Journal on Wireless Communications and Networking*, *2018*(1), 1-18. https://doi.org/10.1186/s13638-018-1044-2.

[34] Feltrin, L., Buratti, C., Vinciarelli, E., De Bonis, R., & Verdone, R. (2018). LoRaWAN: Evaluation of link-and system-level performance. *IEEE Internet of Things Journal*, *5*(3), 2249-2258. https://doi.org/10.1109/TETC.2013.2278698.

[35] Famaey, J., Berkvens, R., Ergeerts, G., De Poorter, E., Van den Abeele, F., Bolckmans, T., ... & Weyn, M. (2018). Flexible multimodal sub-gigahertz communication for heterogeneous internet of things applications. *IEEE Communications Magazine*, *56*(7), 146-153. https://doi.org/10.1109/MCOM.2018.1700655.

[36] Muthanna, M. S. A., Wang, P., Wei, M., Abuarqoub, A., Alzu'bi, A., & Gull, H. (2021). Cognitive control models of multiple access IoT networks using LoRa technology. *Cognitive Systems Research*, *65*, 62-73. https://doi.org/10.1016/j.cogsys.2020.09.002.

Seyed Mehdi Mousavi was born on June 22, 1976. He graduated in Communication Engineering at the University of Tehran in 1999 (Iran); then he received M.Sc. in Security Communication Engineering from Iran University of Science and Technology, in 2010. He is an Assistant Professor at Payame Noor University since 2010 (Iran). He is a Ph.D. candidate from Islamic Azad University, Science and Research Branch, Tehran, Iran. His main research topics of interest are Telecommunication Networking, Network Security, IP Telephony, Video Streaming, Network QoS Management, and IoT.
Email: m.mousavi55@gmail.com

Ahmad Khademzadeh is currently working as a Professor for Computer Engineering Department, Iran ICT Research Center, Tehran, Iran. He graduated in the Theory of Information and Coding from Kent University of England. He has more than 40 journal articles, more than 40

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conference papers and more than 80 postgraduate dissertations. He also won the first rank of the Iran best researcher in 2003 and in the Iran sixth Kharazmi Festival, he won the title of the third rank of the initiative.
Email: zadeh@itrc.ac.ir

Amir Masoud Rahmani is currently working as a Professor for Islamic Azad University, science, and research branch, Tehran. He is the author/co-author of more than 220 publications in technical journals and conferences. His research interests are in the areas of Distributed Systems, Wireless Sensor Networks, Internet of Things, and Evolutionary Computing.
Email: rahmani@srbiau.ac.ir

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