ICIC Express Letters
Part B: Applications
Volume **13**, Number **4**, April **2022**

ICIC International ©2022 ISSN 2185-2766
pp. 355–362

5G UTILIZATION ANALYSIS FOR SMART GRID APPLICATIONS COMPARED TO WIMAX AND LPWAN TECHNOLOGIES

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Received August 2021; accepted November 2021

Abstract. *This paper aims to analyze the technical feasibility of applying 5G cellular technology in Smart Grids applications through the comparison among long-range communication technologies, such as NB-IoT, Sigfox, LoRa and WiMAX, which are technologies widely used in this context. Definitions and characteristics of these technologies are described and comparisons are performed among communication features such as latency, coverage distance, bandwidth, costs, energy consumption, and scenarios of application, and advantages and disadvantages for each one. At the end, all data are compiled and the feasibility of 5G application is justified.*
Keywords: 5G, LoRa, LPWAN, NB-IoT, Sigfox, Smart Grids, Telecommunications technologies, WiMAX

1. **Introduction.** According to the U.S. Department of Energy, "A smart grid uses digital technology to improve the reliability, flexibility, security, and efficiency of the electricity system – key ingredients in the ongoing modernization of the electricity delivery infrastructure" [1].

In Smart Grids Opportunities Developments and Trends, a *Smart Grid* is defined as: "A smart grid uses sensing, embedded processing and digital communications to enable the electricity grid to be observable (able to be measured and visualized), controllable (able to manipulated and optimized), automated (able to adapt and self-heal), fully integrated (fully interoperable with existing systems and with the capacity to incorporate a diverse set of energy sources)." [2].

The Smart Grid is an opportunity to use new ICTs (Information and Communication Technologies), but any significant change may have a high cost and then must have strongly reasoned technical justifications [3]. In most cases, wireless technologies have advantages over wired technologies because their deployment cost is lower and coverage in remote areas occurs immediately [4].

Smart Grids are commonly divided into four levels of communication: Wide Area Network (WAN), Field Area Network (FAN), Neighborhood Area Network (NAN) and Home Area Network (HAN). The interaction among these levels is illustrated in Figure 1.

DOI: 10.24507/icicelb.13.04.355

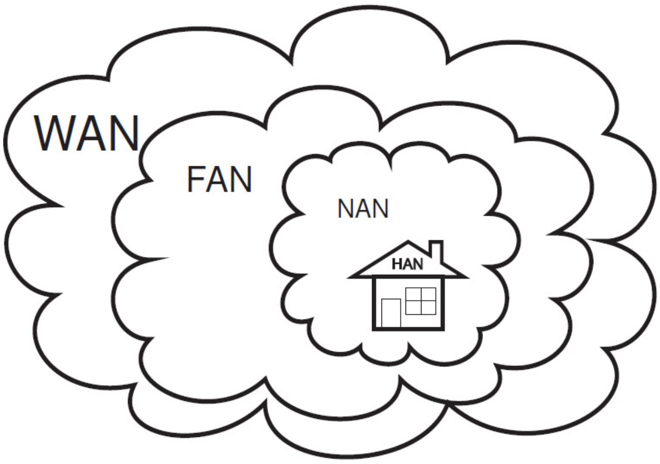

Figure 1. Communication levels of a Smart Grid network [6]

HAN is the consumer unit's own network and has a low reach. NAN is communication between neighboring devices. FAN and WAN are higher levels of communication, so they need communication technologies with bigger coverage [5]. In this way, the need to long-range technologies for solutions in Smart Grids is evidenced, such as smart metering, monitoring of power quality parameters, control of protection devices, and configuration of field devices [6].

Beyond the coverage, some other relevant operational requirements of a Smart Grid are latency and bandwidth [7]. Deployment, maintenance costs, and energy consumption are also important factors in any technological solution.

This article has the objective of support analysis of feasibility of applying 5G technology in smart grid applications. In order to reach that, data from five long-range wireless communication technologies are presented, the main ones being 5G, three Low Power WAN technologies – LPWAN (Sigfox, LoRa and NB-IoT) and WiMAX. These technologies fully or partially meet the aforementioned requirements. They were selected because WiMAX and LPWAN are already being used in Smart Grid context, while the 5G deployment is growing worldwide, what may impact decisions of which technology should be used in new smart grid projects.

Prior to this work, it was presented in [4] a survey on 5G application, applied to Smart Grid networks, but the comparisons presented were concentrated on cellular technologies, such as Long Term Evolution (LTE). In [8], a survey presented a great potential of 5G application for demand response applications. In [9], authors presented a lot of technical information about communication technologies for Smart Cities and Smart Grids, but no information about 5G was presented in those applications. In [10], several features of 5G applied to Power Internet of Things (PIOT) were presented, but the comparisons given were related only to other cellular technologies. In [11], a state-of-the-art survey presented features of wired and wireless technologies for backhaul applications, for instance, LTE, 5G, WiMAX and the upcoming 6G, but there is no mention to any LPWAN technology. In [12], a study demonstrated deterministic latency framework for 5G networks, but the smart grid scenario was note analyzed. Therefore, this article complements, updates, and compiles technical information of 5G utilization in Smart Grids applications through comparisons among different communication technologies under operational criteria for Smart Grid applications, which shows a real possibility of applying 5G in Smart Grids.

This work was divided as follows. Chapter 1 presents an introduction to long-range technologies applied in Smart Grid, as well as a literature review on 5G. In the following session, a theoretical foundation is made about the technologies to be mentioned. In Chapter 3 comparisons are made among the technical requirements of a communication network for Smart Grid and the characteristics of each type of technology. Finally, Chapter 4 brings the conclusions regarding the application of 5G in different contexts of the Smart Grid and proposes future researches.

2. **Theoretical Foundation.** In order to properly analyze communication technologies, it is necessary to know some technical characteristics of each one of them, which are presented below.

2.1. **5G communication.** 5G has the multi-functionality and flexibility to further support many critical issues related to cost analysis and power management applications. The ultra-low latency and massive access network of resources can effectively meet the connection requirements of the central supervisory control of services in the electrical grid of a smart grid [4].

The network slicing technology was first implemented in 5G and provides security and isolation with reliability similar to dedicated networks such as optical fiber, but with significantly reduced deployment cost. A network slice is a virtual allocation of communication resources with an independent lifecycle and customizable operating requirements according to different network levels. The 5G network slicing also enables the creation of special networks based on demand in the established requirements. Multiple slices of the network can be managed in a unified way, effectively reducing operational costs [13].

In addition to the possibility of network slicing, 5G communication technology has other features for applications in a smart grid:

- 5G can be up to 100 times faster than 4G, with data rates of up to 10 Gb/s, capable of supporting UHD (Ultra High Definition) videos, virtual reality applications, web pages and monitoring of smart vehicles;
- Ultra-low latency lower than 1 ms;
- Several billion applications and hundreds of billions of machines;
- Energy usage per bit can be 1000 times less, which improves the technical feasibility of battery-operated devices [14].

5G networks allow Intelligent Electronic Devices (IED) to be interconnected more quickly in order to monitor the generation and consumption of electricity more efficiently and individually by each city or consumer group. This helps in reducing energy cost [4].

5G networks can be built by using small cell networks encompassing up to 100 times more antenna locations than 3G/4G networks, which makes it possible to increase the number of devices that would be connected to the network of the future [14].

Figure 2 illustrates the main advantages of using 5G communication technologies used in smart networks [4].

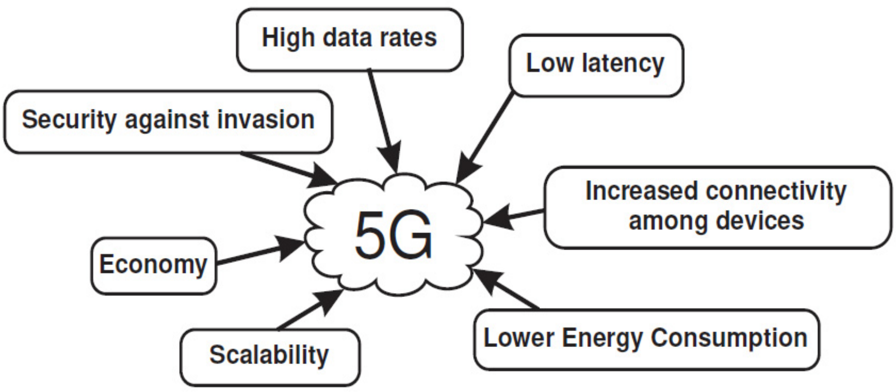

Figure 2. Benefits of 5G networks in Smart Grids

2.2. **LoRa communication.** The Long Range (LoRa) technology is included in the class of Low Power Wide Area Network (LPWAN), which was developed to meet applications where medium and long-range wireless connectivity is desired, and at the same time with low energy consumption. It uses a spread spectrum modulation in the GHz band to allow long range coverage, in addition to supporting a network with a large number of devices [15].

The basic structure of a LoRa network is usually composed of a network and application server, a hub or gateway, and the end devices. When considering transmission aspects with this technology, there are two streams of data transmission. The first is Uplink, when the end node transmits data to the gateway, and the second is Downlink, when the gateway transmits information to the end node. In this type of network, communication does not occur directly between end devices [15].

LoRa wireless technology uses low power transmission of small data packets (0.3 kbps to 37.5 kbps) to a long-distance receiver [15].

2.3. **Sigfox communication.** Sigfox has some characteristics similar to LoRa and is also considered an LPWAN technology. One of the common aspects of the two technologies is the use of unlicensed spectrum for operation [16]. This allows both to be used to exchange information over long distances, without the use of cellular networks, as they have their own structure.

As a result, the measurement data obtained through sensors reaches the cloud via a gateway. Cloud servers are responsible for discovering the collected data and using them in their different applications. So there is an economical and simple way to install smart grids [17].

Sigfox wireless systems send small 12-byte packets at very slow rates, around 300 baud. This allows the increase of transmission range, enabling communications over long distances. As a result, Sigfox is not indicated for transmitting large data loads as the packet contains the capacity of only 12 bytes. With this protocol, it is possible to send just over 140 messages per day, resulting in an average of 6 sends per hour. In addition, the recognition of transmission or bidirectional communication is not performed, and then, some limitations in the security, reliability and performance requirements are pointed out [15].

2.4. **NB-IoT communication.** Communication via NB-IoT differs slightly from LPWAN radio technologies as it is designed to allow communication between a large number of devices and applications through mobile communication [18]. As a result, it operates based on existing LTE network functionalities [19]. Some simplifications were made to this standard in order to better serve devices with low computational power and low energy storage capacity.

NB-IoT is suitable for use in a subset of LTE network – its physical layer limits the bandwidth to a single narrowband of 200 kHz used for both sending and receiving data. Communication via NB-IoT is able to provide good coverage and uses the same network architecture as LTE with some optimizations for IoT applications. The ranges in which this narrow band is generally applied are 0.7 GHz, 0.8 GHz and 0.9 GHz [15].

To compare the mentioned LPWAN technologies, Table 1 brings a comparison between the different technologies in terms of their rates, sensitivity, bandwidth and modulation [17].

2.5. **WiMAX.** The WiMAX technology, which is described in the IEEE 802.16 standard, was developed with the intention of reaching large distances, which would make it a suitable technology for WAN applications. However, it can be used for either NAN, FAN and WAN [20]. The WiMAX technology brings many benefits to Smart Grids, which allowed its use in all levels of communication: WiMAX can be used for reading wireless

Table 1. Comparison of specifications of LPWAN technologies [17]

Technology	Sigfox	LoRa	NB-IoT
Data rate	100 bps	0.3-38.4 kbps	100 kbps
Effective bandwidth	300 Hz	3 kHz	3 kHz
Frequency band	Sub-GHz ISM	Sub-GHz ISM	Licensed
Standard transmission power	15 dBm	20 dBm	23 dBm
Maximum loss	162 dB	157 dB	160 dB
Reception sensitivity	−147 dBm	−137 dBm	−137 dBm
Standard	No	LoRaWAN	LTE

meters, real-time charging, detection of power outages and other monitoring functions [21].

Among the main characteristics of WiMAX technology for Smart Grids, there is low latency, large bandwidth, easy deployment, long range (16 to 50 km approximately) and cheap physical structure when compared to other technologies, such as optical fiber. WiMAX also has closed-loop power control, high Quality of Service (QoS) and message prioritization, a very important function for Smart Grids, since events present in the electricity grid can have different priorities [7]. In addition, WiMAX can work with security protocols and is scalable, a feature that allows expansion of the communication network [21].

WiMAX communication technology is consolidated as one of the most suitable technologies when looking for long range, high data traffic, and low deployment cost, but it is necessary to pay attention to the energy consumption of the network elements, which is, in general, high [20].

WiMAX technology has its own operational profile for Smart Grids, called WiGRID, which allows an optimized configuration by adjusting several parameters, such as duration and size of communication frames, scheduling strategies and data traffic mapping [5].

3. **Application Analysis.** WiMAX technology has gained wide support within the context of smart grids in a time when there was the expansion of latest technologies as 5G and LPWAN technologies. Thus, at that time, WiMAX stood out positively for these applications. This article aims to update comparisons between current technologies and analyze the viability of 5G technology for Smart Grids. In this way, several comparisons are made to verify the technical feasibility.

3.1. **Latency.** As mentioned in the previous topics, the communication technology via 5G has an ultra-low latency of less than 1 ms. WiMAX typically has less than 100 ms latency [5]. NB-IoT has a typical latency of less than 10 s, which is still less than LoRA [18]. Sigfox has an average latency of up to 2 s [15], so it is considered that 5G would be a better choice for low latency applications. Anyway, it is worth noting that latency in a network is directly proportional to the number of connected devices, i.e., in the future, when 5G networks are being used on a large scale, these statements can be discussed again.

3.2. **Bandwidth.** One of the biggest benefits of 5G is the possibility of massive communication with low latency. In this way, 5G technology becomes a great competitor to WiMAX, which also allows high communication rates. LPWAN technologies, in general, have much lower communication rates [20].

3.3. **Coverage.** All the mentioned technologies are suitable for use in NANs and WANs [20]. Furthermore, it is known that the range of wireless networks depends on the environment in which the antennas are installed, so this criterion is not decisive when choosing any of the technologies.

3.4. **Deployment cost.** The origin of the cost of deploying a 5G network for energy companies is quite similar to the one of NB-IoT technology. These two technologies are implemented by telecommunications operators, eventually with a government subsidy. Energy companies then need to hire a Virtual Private Network (VPN) and bear the data and chip costs for the network devices to work. All these costs are negotiated between telecommunications operators and electricity concessionaires. Thus, the utility's telecommunications infrastructure costs are mostly field equipment [21].

It has not yet been possible to make an accurate survey of the costs of network usage due to the fact that 5G technology is still in the process of being widely implemented [21].

When using technologies such as LoRa, Sigfox and WiMAX, the utility is responsible for the entire infrastructure of radios, repeaters and antennas [21].

Under these conditions, even a telecommunication system via WiMAX, which is considered to be a system with a low implementation cost, can be the most expensive among the mentioned technologies [21].

3.5. **Energy consumption.** The 5G technology brings the proposal of a significant reduction in consumption when compared to 4G, which has high energy consumption. WiMAX has high power consumption, comparable to 4G. LPWAN technologies have very low consumption [21].

Table 2 summarizes all presented information.

Table 2. Data comparison of all presented technologies

	5G	**WiMAX**	**LoRa**	**Sigfox**	**NB-IoT**
Latency	< 1 ms	< 100 ms	May be > 10 s	< 2 s	< 10 s
Bandwidth	High	High	Low	Low	Low
Coverage	Long	Long	Long	Long	Long
Deployment costs	Telecommunication operator	Utility	Utility	Utility	Telecommunication operator
Energy consumption	Medium	High	Low	Low	Low

4. **Conclusions.** This paper presented several technical characteristics of wireless communication networks for Smart Grids applications. Considerations were made on the 5G technology compared to Sigfox, LoRa, NB-IoT, and WiMAX, which is already widely used.

It could be concluded that 5G communications technology has great potential for new deployments instead of WiMAX. In addition, 5G brings several technical advantages over WiMAX, which makes it more interesting for the Smart Grids context, such as low latency, higher bandwidth, lower deployment costs and lower energy consumption. It is important to emphasize that WiMAX allows for a customization of the use of technology to be more suitable for Smart Grids according to the needs of companies, which is a very positive point. On the other hand, 5G features network slicing, which also has very interesting applications for energy companies, such as isolating the communication network.

LPWAN technologies bring significant advantages from the perspective of the cost of maintaining the network, as they have low energy consumption and a low implementation cost, but they may be inadequate in contexts where large amounts of data are needed or in contexts that require extremely long ranges.

It is estimated that the 5G communication technology could be widely used in Smart Grids soon, since, technically, there are no significant impediments to do so. This implementation will depend, as well as of policy and regulatory aspects, almost exclusively on negotiations between telecom operators and power companies.

Future researches will be needed when 5G technology is fully deployed worldwide, because all costs will be presented for each country or region and all behaviors of a widely used network will be properly measurable. 6G technology is also being studied and may have some impact on smart grid communications technologies in the coming years.

Acknowledgment. The authors gratefully acknowledge the financial support in part of CAPES – Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brazil – Finance Code 001, CNPq – National Council for Scientific and Technological Development – Brazil, INERGE and FAPEMIG.

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