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Research Article

Wireless Communication Technologies for IoT in 5G: Vision, Applications, and Challenges

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Communication technologies are developing very rapidly and achieving many breakthrough results. The advent of 5th generation mobile communication networks, the so-called 5G, has become one of the most exciting and challenging topics in the wireless study area. The power of 5G enables it to connect to hundreds of billions of devices with extreme-high throughput and extreme-low latency. The 5G realizing a true digital society where everything can be connected via the Internet, well known as the Internet of Things (IoT). IoT is a technology of technologies where humans, devices, software, solutions, and platforms can connect based on the Internet. The formation of IoT technology leads to the birth of a series of applications and solutions serving humanity, such as smart cities, smart agriculture, smart retail, intelligent transportation systems, and IoT ecosystems. Although IoT is considered a revolution in the evolution of the Internet, it still faces a series of challenges such as saving energy, security, performance, and QoS support. In this study, we provide a vision of the Internet of Things that will be the main force driving the comprehensive digital revolution in the future. The communication technologies in the IoT system are discussed comprehensively and in detail. Furthermore, we also indicated indepth challenges of existing common communication technologies in IoT systems and future research directions of IoT. We hope the results of this work can provide a vital guide for future studies on communication technologies for IoT in 5G.

1. Introduction

The development history of mobile communication systems demonstrated that aim to meet the requirements of humanity, the data rate of mobile communication is constantly being improved and achieved breakthrough results. Mobile generations have evolved through 5 periods, starting from 1G to the current 5G [1]. Network generations from 1G to 3G have shown the continuous evolution of services and speeds. The 4G was proposed in the early 2000s. 4G was the first network generation entirely based on the IP packet switching method [2]. After about ten years of implementation, the former advantages of 4G have converted into disadvantages. Nowadays, 4G has access speed has become too low with high latency [3]. Humanity needs a solution to connect with data rates up to Gbps. The advent of the next-generation network called 5G in the early 2020s marks a comprehensive digital society. In particular, in 5G, a new concept is considered the Internet of Things (IoT) [4, 5]. IoT is an integrated system of advanced technologies and solutions that allows devices, people, platforms, software, and solutions to be connected through the Internet [6, 7].

According to Cisco, more than 500 billion devices will be connected to the Internet by 2030. These devices will be endogenously equipped with IoT modules that allow device-to-device (D2D) communications to each other, forming IoT networks [8]. IoT applications will be deployed in almost all humanity domains, including smart cities [9, 10], smart transportation [11, 12], smart agriculture [13, 14], and smart homes [15]. In [16], we presented a detailed survey of IoT applications for humanity. We illustrate several typical IoT applications as in Figure 1.

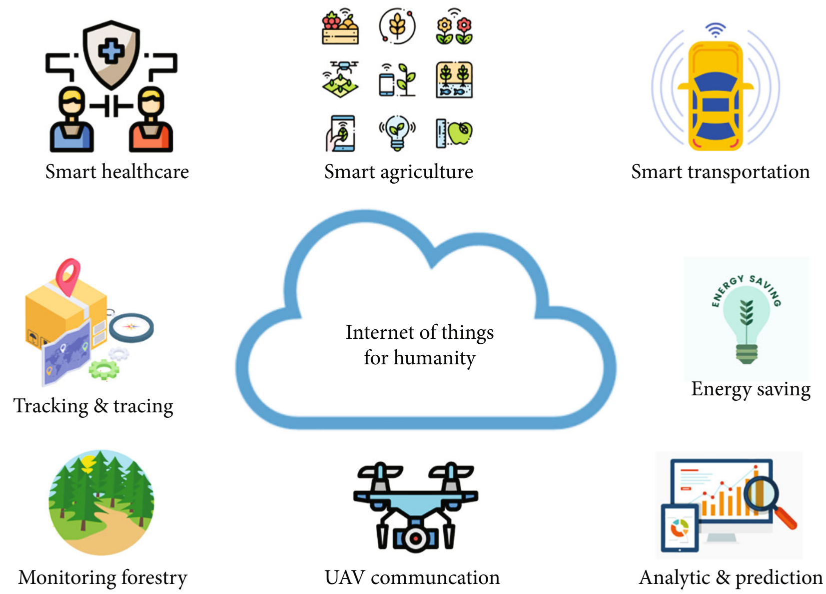

Figure 1: An illustration of IoT applications for humanity.

However, the survey results also showed that IoT networks in 5G have a series of challenges such as performance improvement, support QoS, saving energy, privacy, and security [17, 18]. Communication solutions including architecture, routing algorithm, protocol, and spectrum have been proposed to solve these problems. In this study, we conduct a comprehensive survey of communication technologies for IoT in 5G. The main contributions of this survey are listed as follows:

(i) The vision of the Internet of Things in 5G: architecture and research timeline

(ii) A comprehensive survey of the recent communication technologies for IoT in 5G

(iii) The breakout technologies and solutions for IoT in 5G

(iv) Challenges and attractive research topics in the future of communication for IoT

(v) The vision of the Internet of Things in 5G

The evolutionary history of network generations has proven that each generation is born to correct the weakness of previous generations and do some things that the previous generation could not do [19]. In the early 2020s, the Internet of Things concept was born simultaneously with the emergence of 5G [20]. Therefore, to define the vision of IoT in 5G, we need to clarify the advent context of IoT in 5G.

For the convenience of following the article, we have compiled the acronyms in Table 1.

1.1. Forming of IoT in 5G. The development history of mobile communication systems began in the early 1980s. During its development, mobile radio communication systems always tend to integrate all systems. End-user devices are smarter more and more, lighter, save energy, support all types of data such as voice, video, and real-time multimedia applications. The data rate and bandwidth increase with costs decrease. The 1G–3G network generations are standardized and deployed widely worldwide, in references [1, 21]; so, we will not consider these issues to focus on presents the 4G network generation.

The 4th mobile network generation (4G) is formed after 3G and before 5G. Besides the provided services of 3G, it also provides added services such as broadband Internet access, IP phone (VoIP), video conferencing, online games, high-definition Internet TV, 3D TV, and cloud computing. The two technologies were standardized for 4G as Wimax and LTE [21]. One difference with previous generations, 4G unsupports the traditional circuit switching mechanism but relies entirely on IP protocol with the packet switching mechanism. Aim to speed up data transmission, spectrum modulation technologies of previous generations are replaced by OFDMA technology, combined with MIMO multipoint transceiver mechanism and smart antenna. [22]. As a result, the bit rate in 4G is significantly higher than in 3G.

With many advantages mentioned above, 4G has become a pioneering technology and commercialized in many countries. In Vietnam, 4G was deployed in 2016 [23]. However, after many years of deployment, 4G has revealed the limitations of this network generation. According to Cisco, over 500 billion devices will be connected to the Internet in the future. This is beyond the provided capacity of 4G [24]. Moreover, the delay of 4G is too large for the real-time applications, approximately 10 ms, and the data rate of 4G is relatively low, approx. 3 (Mbps). With the number of devices increasing hundreds of times today, 4G will consume a huge amount of energy.

The limitations of 4G were indicated that the advent of 5G is an inevitable trend. Humans need a new network

Table 1: Acronyms used in the survey and definations.

Acronym	Definition
3GPP	3rd generation partnership project
5G	5th generation mobile networks
AAC	Adaptive admission control
AI	Artificial intelligence
ANN	Artificial neural network
AR	Augmented reality
D2D	Device-to-device
D2D	Device to device
eNB	Evolved node B
GPRS	General Packet Radio Service
GSMA	Global System for Mobile Communications
IIoT	Industrial Internet of Things
IoT	Internet of Things
IP	Internet protocol
LoRa	Long range
LoRaWAN	Long Range Wide-Area Network
LPWANs	Low-Power Wide-Area Technologies
LTE	Long-term evolution
MIMO	Multiple in, multiple out
NB-IoT	Narrowband IoT
NFC	Near field communication
OFDMA	Orthogonal frequency-division multiple access
QoS	Quality of service
RFID	Radio frequency identification
SC-FDMA	Single-carrier FDMA
SDN	Software-defined networking
UAV	Unmanned aerial vehicle
VoIP	Voice over internet protocol

generation that the data rate increases hundreds of times faster, but energy consumption reduces many times compared to 4G. Some countries such as China, Korea, the United Kingdom, and the United States are currently pioneering in the studies and deployment of 5G. Although still not yet official standardized, GSMA and some organizations and suppliers such as Ericsson and Huawei have proposed the standard of 5G network generation [25] as follows:

Aim to achieve these goals, in Table 2, many breakout technologies and solutions need to be implemented synchronously. However, like previous generations, the improvement of the radio access layer has always been a significant challenge to meet the goals of 5G. In this study, we approach 5G from an Internet of Things perspective. The concept of IoT was first mentioned in 5G. IoT is an advanced technology that allows things, machines, devices, solutions, and people to connect through the Internet. IoT is expected to become popular in all areas serving people, such as smart agriculture, smart transportation, smart cities, health, rescue and disaster recovery, retail, management house, and green energy. A very diverse survey of IoT applications is presented in [26].

Table 2: Main characteristics of 5G network generation.

Characteristics	Goal
Mobile access speed	1 Gbps
Fixed access speed	1-10 Gbps
Data transmission delay	1 ms
Reliability	99.999%
Energy consumption	Reduce many times compared to 4G

1.2. The Architecture of IoT in 5G. IoT in the 5G framework consists of main four-layer architecture, as shown in Figure 2, and is related to data collection, processing, analysis, and sharing of information between equipment and communication networks.

(i) Thing layer: This layer includes physical systems such as actuators, devices, sensors, and communicates with the network layer

(ii) Network layer: The network layer consists of two sublayers: (1) low power wide area technologies (LPWANs) such as SigFox, LoRa, ZigBee, NB-IoT, and (2) backhaul-based connections of 5G. In this study, in order to focus on detailing communication solutions in IoT, communication technologies in the backhaul layer are not within the scope of this research

(iii) Middleware layer: this layer is considered the heart of the network. The IoT framework focuses on advanced technologies and solutions as fog computing, edge computing, cloud computing, AI vision, and big data analytics are deployed

(iv) Application layer: this layer presents IoT applications that are deployed in a series of domains as management factories and buildings, agriculture, traffic system, and IoT ecosystems. This layer integrates all solutions, technologies, and applications to interact with humans through the Internet connection

A specific illustration of this architecture is presented in Figure 3. The sensor devices of IoT applications interact with the IoT gateway based on low-power communication networks such as SigFox, LoRa, or NB-IoT. These IoT gateways collect information from IoT devices and then transmit it to the Cloud through the 5G backhaul communications. In the middleware layer, the collected data is processed and stored, combining autonomous decision-making systems or human controls to make under layer tasks.

1.3. Research Timeline IoT in 5G. Nowadays, study activities on different aspects of the Internet of Things in 5G are exciting in both academic research and industry. Some of the top mobile telecommunication corporations and excellent research labs perform studies and experiments to provide applications and solutions of IoT in 5G.

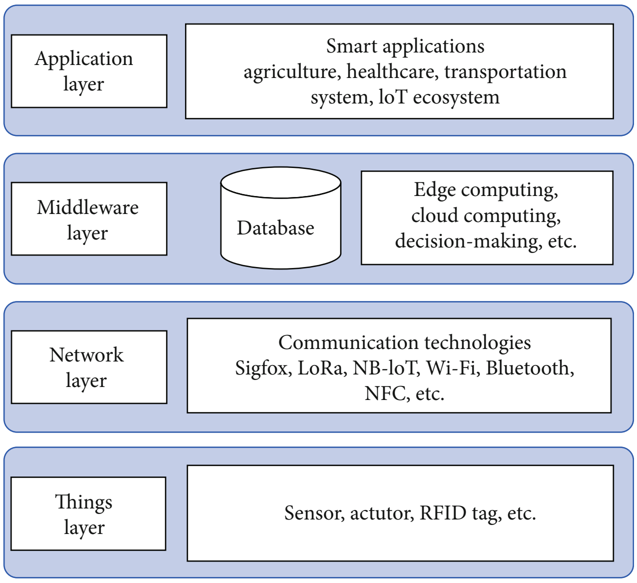

Figure 2: An illustration of the IoT in 5G architecture.

1.3.1. Intel. This corporation has pioneered in the IoT field. The company predicts that IoT devices will generate over 55% of global data by 2025. In order to accelerate the application of IoT in various areas serving humanity, Intel is developing an IoT ecosystem at all layers of the IoT architecture with the key technologies and solutions [27] as follows:

(i) In thing layer, Intel providers unique performance scalability with four processor families for IoT applications. Besides, processors of Intel run a variety of operating systems such as Linux, Microsoft, and Google

(ii) In network layer, Intel supports many networking interfaces and protocols to provide the necessary connectivity. Besides, Intel also provides Gateway solutions for the IoT

(iii) In middleware layer, Intel server technology is extensively used in the network and cloud infrastructure. Moreover, Intel is focusing on three IoT computing projects, including edge computing, cloud computing, and AI and computer vision

(iv) In application layer, Intel provides foundations to support the IoT application in various other domains, such as Figure 4

1.3.2. Samsung. According to Samsung, the total number of IoT devices is expected to increase to 21.5 billion by 2025. The number of devices also increases to 34.2 billion if it includes smartphones, laptops, and tablets. Furthermore, Samsung also forecasts that the global IoT market will archive around $1.600 billion. Relying on the expectation that all devices will be connected to the Internet, Samsung has built IoT ecosystems in 5G to realize aspirations such as smart homes, smart cities, smart factories, healthcare, smart agriculture, and logistics [28]. Some of the recent developments in the field of IoT are as follows:

(i) In application layer, Samsung is providing IoT solutions that allow users to control home appliances. The Samsung electronic devices such as TVs, washing machines, and refrigerators can be controlled by remote based on a Samsung smartphone

(ii) In middleware layer, Samsung is implementing research projects related to optimal computing solutions, specifically edge computing, cud computing, and AI vision

(iii) In thing layer, products and devices designed for Samsung IoT platforms, including phones, tablets and wearables, digital signage, and automation solutions. In particular, Samsung designed the unique IoT modules, called Samsung ARTIK modules, which can be customized based on the size, ability, and capabilities of the Samsung products. Moreover, the Samsung ARTIK Smart IoT platform combines open-source modules and cloud services with an ecosystem of tools and partners that is motivation to drive the development of the IoT in 5G. Figure 5 is an illustration of the Samsung Artik 530 development kit

1.3.3. Ericsson. According to Ericsson, the expected IoT numbers of connections would increase over 3.5 times from about 1.7 billion in 2020 to approx 6 billion by 2026. Erricson also forecasts there will have over 24 billion interconnected IoT devices Internet by 2050. Consequently, almost everything is around us as home appliances, vehicles, traffic lights, personal devices, learning devices, and health monitoring would be connected to the Internet. This will be a very exciting area both in academic and industrial research in the coming years. With the ambition to connect anything, anywhere, Ericsson is driving the growth of the IoT through its major contributions in the domain of real-time network performance and cloud computing solutions [29]. Some researches dedicated by Ericsson for IoT in 5G are as follows:

(i) In application layer, besides developing IoT solutions and applications for a wide range of fields such as healthcare and smart agriculture, Ericsson developed an IoT Accelerator Developer Portal to support the development of IoT solutions for the community of application developers worldwide, as presented in Figure 6

(ii) In network layer, Ericsson has focused on researching spectrum sharing solutions, exploiting mmWave, THz frequency bands, and intelligent communication solutions between devices

(iii) In middleware layer, Ericsson promotes research into architectures and solutions of cloud computing and edge computing

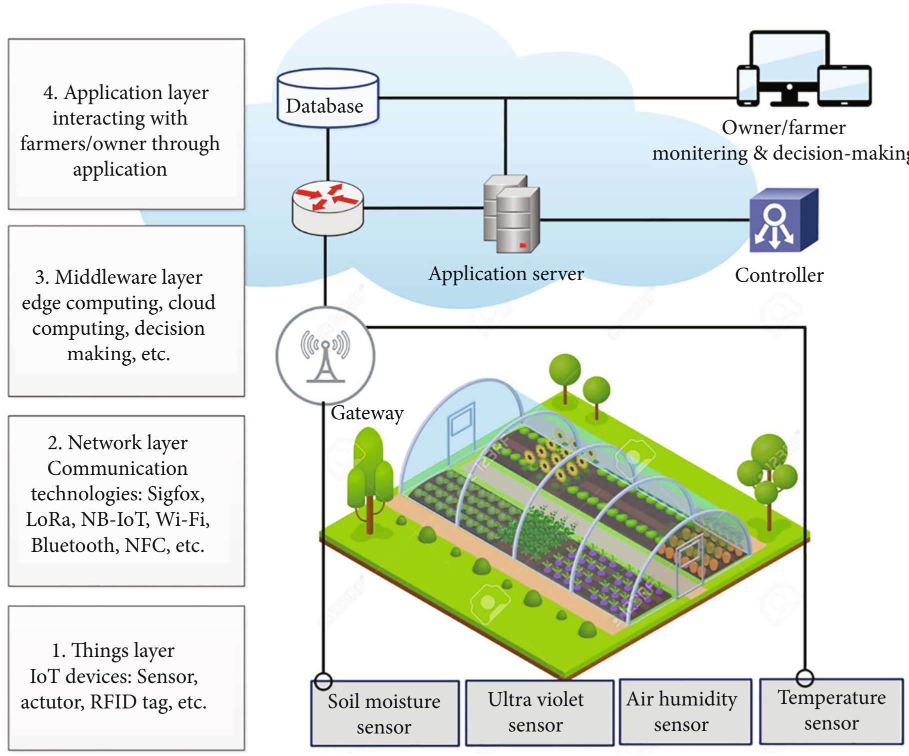

Figure 3: An illustration of practise IoT structure for smart agriculture area.

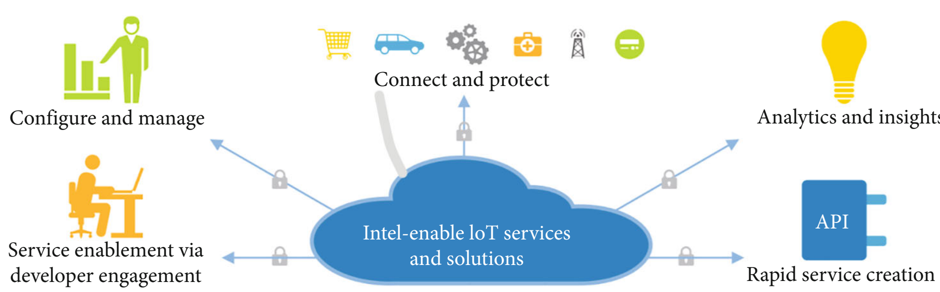

Figure 4: The foundation for connected IoT.

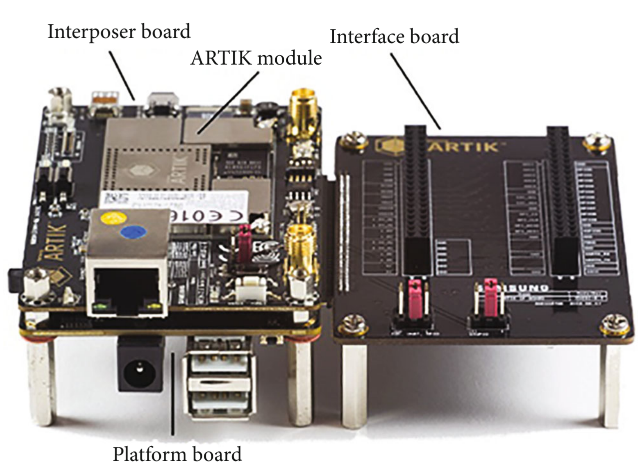

Figure 5: An illustration of the Samsung Artik 530 development kit.

1.3.4. Huawei. This corporation is a pioneering provider of communication solutions for IoT in 5G with a very diverse IoT ecosystem. Huawei has developed a Huawei IoT Connection Management Platform that aims to provide a full connection between people and things and fast integration for the vertical industry applications.

According to Huawei, promoting the development of IoT is based on five factors: (1) flexible deployment, (2) multiple connections, (3) intelligent management, (4) data security, and (5) open ecosystems. Reply to these factors, Huawei is driving the development of IoT through a series of significant contributions in all layers of IoT architecture, from the things layer to the application layer [30], as presented in Figure 7. Along with the achieved breakthrough study results by top telecommunication corporations, a series of research labs around the world are also driving the research process to find promising solutions for IoT in 5G aim enhance data rate, exploit spectrum more efficiently, extend communication distances, optimize energy consumption,

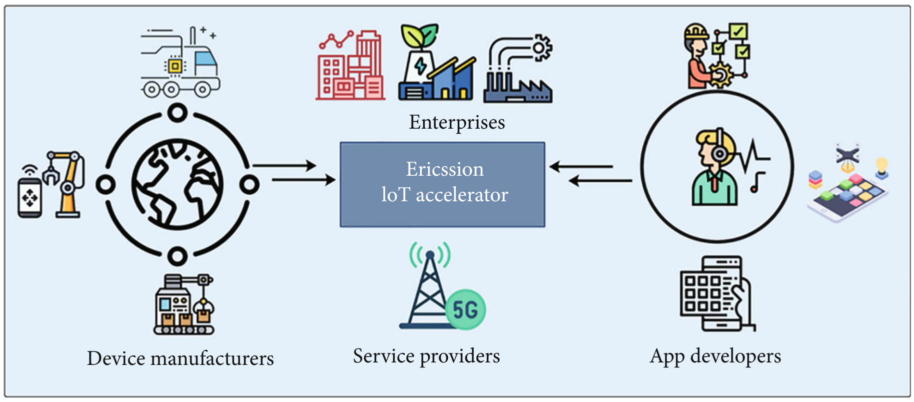

FIGURE 6: An illustration of IoT Accelerator Developer Portal.

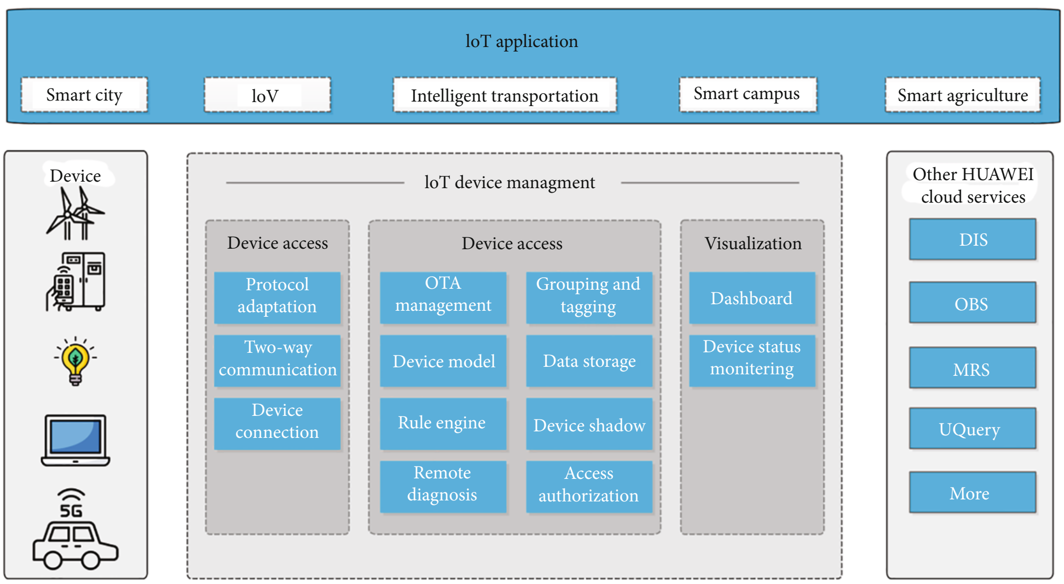

FIGURE 7: An illustration of solutions and products' architecture in the IoT domain of Huawei.

and extend scale networks up to hundreds of billions of Things. IoT in 5G could be the most revolutionary technology in the communication and information technology area. It could be applied in a series of different domains from popular applications in life such as payment utilities, smart retail, manage home appliances to expert apps such as self-driving vehicles, monitoring traffic status, collision warning between vehicles and monitoring, and controlling green energy systems, smart cities management. In the agriculture area, IoT can also be applied in applications such as forestry management, farm management, monitoring forest fire, tracing, and tracking products. In the industrial area, actuators and robots with the support of AI technology can perform tasks day and night replace humans with extremely high productivity and accuracy. It realizes the dream of smart and green factories.

2. Survey of Recent Communication Solutions

Advances in the semiconductor, electronics, and automation industries are driving the development of communication solutions for IoT in 5G. These solutions are smarter, more reliable, robust, high data rate, and energy saving. As a result, various low-power communication technologies have been proposed for IoT in 5G, such as SigFox and LoRa. Survey results have demonstrated that low power technologies are suitable for IoT 5G networks due to their unique characteristics such as wide coverage, low power, high energy efficiency, and suitable data rate. In this section, we present the recently proposed communication solutions for IoT in 5G. We divide these proposals into four categories based on technology. The detailed survey results are presented in the following subsections and are summarized in Table 3.

2.1. SigFox. SigFox technology was introduced in the 2010s to connect low-power devices such as electricity meters and smartwatches, which need to be continuously operated on and have extremely low data rates. SigFox uses the industrial, scientific, and medical radio band, which uses 868 MHz in Europe and 902 MHz in the US with a channel bandwidth of 100 MHz. SigFox uses a wide-reaching signal that passes freely through solid objects, called ultra narrowband and

Table 3: Some typical LPWAN communication technologies for IoT in 5G.

Type	Transmission distance	Type of network	Frequency	Data rate
802.11a/b/g/n/ac	100 m	WLAN	2.4-5 GHz	2-700 Mbps
802.11ah	1000 m	WLAN	Sub-GHz	78 Mbps
802.11p	1 km	WLAN	5.9 GHz	3-27 Mbps
802.11af	1 km	WLAN	54-790	25-550 Mbps
SigFox	Rural: 50 km Urban:10 km	LPWA	Zwave	100-600 bps
LoRaWAN	20 km	LPWA	Sub-GHz	0.3-100 Kbps
NB-IoT	35 km	LPWA	Zwave	250 Kbps
ZigBee	1 km	LPWA	2.4 GHz	250 Kbps

requires low energy; so, it also is an LPWAN technology. It uses a one-hop star topology. SigFox is used to cover large areas and to reach underground objects. SigFox cells have a coverage range of about 30-50 km in rural areas and reduced to under 10 km in crowded areas. Overall, SigFox enables to provide a wide area network with low-power consumption. Nowadays, the SigFox IoT system has covered around 72 countries with over 1.3 billion of the world population. Several recent IoT applications are based on SigFox communication, as follows:

In [31], Joris et al. (2019) designed an autonomous SigFox sensor node capable collected data from an area of sensors, then transmitting data to the Cloud for smart agriculture applications. Aim to enhance the ability of this system, the sensor nodes are designed to use solar energy. Experimental data show that the system can transmit data every 5 minutes in cloudy conditions. In [32], Lavric et al. (2019) analyzed the responsiveness of SigFox under different scale and density conditions of sensors for IoT networks. The figures indicated that the maximum number of sensors that can transmit data at the same time is approximately 100. The results indicated that, as the number of sensors increases above 100, the network performance could be decreased. Moreover, this study also proposes solutions to improve performance, large-scale, and high-density of sensors in SigFox IoT networks.

In [33], Mikhaylov et al. (2019) evaluated the performance of SigFox communication technology in the real world. Specifically, they deployed a SigFox-based communications network at 311 different locations in Brno city, Czech Republic. Then, they conduct tests to evaluate the performance and characteristics of the radio channel. The experimental results show that the packet delivery ratio achieved over 94% in the urban environment in the real world.

2.2. LoRa. The LoRa is emerging as one of the most promising low-power wide-area (LPWA) communication technologies. It enables the energy-constraint devices distributed over wide-scale areas to establish connectivity at an affordable cost. The LoRa uses a low-power wide-area network modulation technique and unlicensed frequency bands like 433 MHz, 868 MHz (Europe), 915 MHz (Australia and North America), and 923 MHz (Asia). LoRa enables long range transmissions with low power consumption. The LoRa technology covers the physical layer, while other technologies and protocols such as LoRaWAN (Long Range Wide-Area Network) cover the network layer. Depending upon the spreading factor, it can achieve data rates between 0.3 kbps and 27 kbps. However, how to implement a flexible LoRa network with an effective cost is still an open challenge.

In [34], Zhou et al. (2019) designed and introduced an open LoRa system for IoT networks. Contributions of this work include (1) design and hardware implementation of a LoRa gateway, (2) use LoRa open-source codes on GitHub, and (3) improve server LoRa through the uses of the messages system for the interaction between modules to guarantee scalability and flexibility. The experimental results have shown that the proposed system has improved the performance of the LoRa network compared to the traditional LoRa network.

In [35], Lee et al. (2018) designed and evaluated the performance of a LoRa mesh network to examine the applicability of LoRa networks for urban scenarios. This work installed 19 mesh LoRa devices in range [800×600] m on a university campus and installed a gateway that collected data at 1-min intervals. The experimental results showed that the proposed LoRa system has an average packet delivery ratio of 88.49%, whereas the star LoRa topology only achieved 58.7% under the same conditions.

The LoRa is one of the most successful technologies of the LPWAN (Low-Power Wide-Area Network) family. It enables robust long-distance low power communications and is proven to be effective in the Internet of Things (IoT) applications. The LoRa is also promising for Industrial IoT scenarios. However, a limitation of LoRa does not offer support to real-time data flows. To solve this problem, In [36], Leonardi et al. (2019) proposed a new medium access strategy for LoRa, called RT-LoRa, which aim to support real-time LoRa-based IoT applications. The simulation results demonstrated that RT-LoRa could support real-time flows for IoT applications.

2.3. Wi-Fi. Wi-Fi is a known-well family of wireless communication technologies based on the IEEE 802.11 family of standards. It is commonly used for local area networks of devices and Internet access within 100 (m). It operates in the 2.4-5 GHz frequency band. Wi-Fi is suitable for short-range communication; so, it is a feasible communication solution for IoT networks.

In [37], Pokhrel et al. (2020) proposed a queue management solution for the home IoT access points based on Wi-Fi. The focus of this work proposal adaptive admission control mechanism at the Wi-Fi access point aims to reduce the response time of the access point. The experiment results demonstrated that the proposed system is more stable than traditional home IoT systems based on Wi-Fi. In [38], Sheth et al. (2019) proposed a saving energy communication solution based on WIOTAP for IoT systems based on Wi-Fi. The focus of this work uses an intelligent Wi-Fi access point. Then, it presents a downlink packet scheduling mechanism to reduce downlink channel access contention and queuing delay of regular stations in IoT systems. The results demonstrated that the proposed system improved over 38% of energy consumption and over 41% of the delay compared to traditional solutions.

Real-time locating and tracking are the most critical problems of IoT applications. GPS-based positioning applications are well known for outdoor environments. However, it is not feasible for indoor scenarios. In [39], Ruo et al. (2019) proposed an IoT solution to tracking and locating indoor based on Wi-Fi signals for indoor environments. The focus of this work uses a message type that is built-in the 802.11-REVmc2 Wi-Fi standard. Then, through measurements of the round-trip time and signal strength to improve the accuracy and ability of the positioning system. Experiment results demonstrated that the proposed system enhanced the performance and achieved an average positioning accuracy of 1.435 m with an update time of every 0.19 s for indoor scenarios.

2.4. ZigBee. ZigBee is a communication technology that uses the IEEE.802.15.4 standard and operates in the industrial, scientific, and medical radio frequency bands. It is a low-power wide-area communication solution for IoT networks. ZigBee technology in IoT networks has advantages compared to other communication technologies because of its simplicity, flexibility, and low cost. The transmission distance of ZigBee is about 100 m, with a data rate that is about 250 kbps, depending on power output and environmental features. ZigBee is typically used in extreme-low data rate networks, short-range, and long-lasting battery life such as home automation, medical device data collection, and industrial equipment control.

In [40], Pirayesh et al. (2021) proposed a ZigBee receiver based on MIMO against jamming attacks for IoT networks. This work designed a prototype of the ZigBee receiver based on MIMO technology and a learning mechanism to mitigate the unknown interference. The experiment results demonstrated that the proposed system could provide an average of over 26.7 dB jamming mitigation capability compared to the traditional ZigBee receiver.

In [41], Farha et al. (2021) introduced a new security schema based on a timestamp against replay attacks for ZigBee networks. This solution improves energy consumption significantly. Besides, to enhance feasibility, this solution uses powered devices to provide energy for power-constrained devices with the current timestamp. The proposal is designed to be suitable for all ZigBee networks. The experiment results indicated that the proposed solution improves significantly against ability reply attacks in the ZigBee-based IoT networks.

In [42], Ali et al. (2019) designed the smart sensors that combined two communication modules include ZigBee and LoRa, to measure temperature and humidity factors for IoT applications. The collected data from sensors are sent to the central receiver unit by using the ZigBee or LoRa transceiver modules. The choice of the communication module can be controlled remote or based on the Cloud. The practical design and experiment figures indicated the benefits of the low-power, long range communication solutions for IoT applications.

2.5. Narrowband Internet of Things. Narrowband Internet of Things (NB-IoT) is a new LPWAN radio technology developed by 3GPP to support massive connections, wide-area coverage, ultra-low power consumption, and low cost for IoT in 5G. NB-IoT is a promising emerging communication technology for IoT in 5G. NB-IoT focuses specifically on indoor coverage, low cost, long battery life, and high connection density. It uses the bandwidth to narrow-band 200 kHz and OFDM modulation for downlink communication and SC-FDMA for uplink communications.

In [43], Chen et al. (2020) designed a prototype NB-IoT network based on open source for IoT in 5G applications. The open-source NB-IoT results from cooperation between three providers, including EURECOM, B-COM, and NTUST, based on the open-source eNB of LTE technology. This work presents a method to use the existing commercial NB-IoT module to transmit the collected data from sensors to the Internet via the open-source NB-IoT network.

In [44], Chen et al. (2019) evaluated the performance and improved NB-IoT protocol for IoT networks in 5G. The focus of this work includes the following: (1) use the stochastic network to analyze the delay metric in the NB-IoT system and (2) improve NB-IoT protocol through the improvement of the k-means algorithm to cluster NB-IoT devices and perform a scheduling strategy based on the priority. The experiment results indicated that the proposed uplink traffic scheduling schema enhanced performance compared to existing uplink traffic scheduling schemas.

In [45], Kanj et al. (2020) introduced a method to design the physical layer of the NB-IoT device. The focus of this work presents the characteristics and the scheduling of downlink and uplink physical channels at the NB-IoT base station and end-user device to help readers without having to read all the 3GPP specifications.

3. Discussions, Challenges, and Open Issues

In this study, we have highlighted the revolutionary contributions of IoT in 5G in a wide range of fields to serve humanity. Low power communication technologies will play an essential role in supporting and driving IoT applications more public. The survey results have indicated that many applications have been presented in Table 4. The proposals are applied in a variety of domains such as environment, city, home, building, factory, and agriculture.

Communication technologies such as ZigBee, SigFox, LoRa, and NB-IoT have advantages such as low energy

Table 4: Statistics of recently proposed IoT applications based on communication technologies in 5G.

Ref. no	Technology	Application domain	Case study: Key focus
[31]	SigFox	Agriculture	This proposal aims to design an autonomous IoT sensor to collect data in smart agriculture based on the solar energy system.
[32]	SigFox	City, industry, building, home, traffic	This research evaluates the performance of the SigFox communication protocol under different scale and density conditions.
[33]	SigFox	City, environment	This research deployed a network system in the real world at 311 locations of Brno city to measure the real performance of SigFox.
[34]	LoRa	City, environment, healthcare, agriculture	This research designs and deployment a LoRa network for performance improvement, flexible, and reduced cost.
[35]	LoRa	Building	This research real deployed a LoRa mesh system on a university campus to consider the real system performance.
[36]	LoRa	Industry	This research introduced a medium access strategy for LoRA, called RT-LoRa, to reduce service response time for real-time IIoT applications based on LoRa communication protocol.
[37]	Wi-Fi	Home	This research introduced the AAC mechanism at the Wi-Fi access point to reduce service response time for home Wi-Fi IoT applications.
[38]	Wi-Fi	Home	This research introduced the Wi-Fi IoT access point (Wiotap) to address saving energy and reducing delay for home IoT applications.
[39]	Wi-Fi	Home	This research introduced a tracking and location IoT solution based on Wi-Fi to improve accuracy and reduce delay indoor environments.
[40]	ZigBee	Security IoT networks	This research designs a ZigBee receiver against jamming attacks for IoT networks based on MIMO technology.
[41]	ZigBee	Security IoT networks	This research proposes a new security schema based on a timestamp against ability reply attacks in the ZigBee-based IoT networks.
[42]	ZigBee	Environment	This research designs an IoT sensor that combines two communication modules, ZigBee and LoRa, to improve energy consumption and performance.
[43]	NB-IoT	IoT ecosystems	This research designs a prototype NB-IoT network based on open source for IoT in 5G applications.
[44]	NB-IoT	IoT ecosystems	This research introduced a scheduling schema to improve the NB-IoT protocol to enhance performance.
[45]	NB-IoT	IoT ecosystems	This research presents how to design the physical layer of the NB-IoT device according to 3GPP.

consumption, large-coverage, use of unlicensed frequency bands, and suitable for the characteristics of IoT networks and increasingly popular applied in IoT applications. Communication solutions of IoT in 5G aim to provide connectivity for IoT applications. With hundreds of billions of IoT devices connected to the network, these technologies face several significant challenges. In our opinion, the two crucial issues are the security-aware and energy efficiency. Then, we present the challenges of communication technologies for IoT applications in 5G and indicate possible research directions.

3.1. Privacy and Security. The Internet of Things development forms a truly open world, where everything is connected to the Internet. Consequently, objects are easily vulnerable to attacks from the Internet. Therefore, according to Roukounaki et al. (2019) [46], privacy and security are the most critical factors to promote the development of IoT applications to become popular. In IoT applications, attacks can be performed in multiple layers, specifically as

(i) *Security for IoT devices*: the IoT devices with low computing capability and massive numbers are unsuitable for setting up robust security algorithms. Consequently, attacks focus on exploiting the vulnerabilities of IoT devices

(ii) *Security for gateway devices*: the gateway devices play an important role in communication between things layer devices and upper layers. As a result, it is the heart of IoT applications. Denial of service attacks or data spoofing always focuses on the gateway of IoT applications

(iii) *Security for devices at the edge*: recently proposed solutions use edge computing technology to reduce service response times for real-time IoT applications. Consequently, the security of edge computing servers is one of the major challenges

(iv) *Security for cloud servers*: with the huge amount of data is provided by IoT devices, cloud infrastructure will be a possible solution in storing and processing big data. Consequently, the security of cloud servers will be one of the significant challenges

In [47], Zhou et al. (2021) presented a survey comprehensive of security logic bugs in IoT devices, platforms, and systems in all layers. In [48], Lins et al. (2021) presented a complete picture of potential threats as well as solutions aimed to mitigate attacks on IoT gateways. In [49], Wang et al. (2018) presented potential risks at the application layer, including data collection, storage, and data processing in the cloud of cloud-based IoT systems. Attacks into cloud servers to gain control or execute tasks to affect autonomous devices in smart factories and farms. In [50], Hassija et al. (2019) presented a diverse survey of attacks and security threats and proposed several architectural solutions to mitigate attacks on IoT systems.

In our opinion, security is one of the most critical problems of communication solutions in the IoT 5G network. This issue will continue to be a research topic timely and attract both academic and industry researchers in the future.

3.2. Energy Efficiency. Assuming that when IoT applications in 5G become popular, tens of billions of IoT devices will operate and transmit data continuously day and night. As a result, it will consume a huge amount of energy while energy resource is exhausted day by day. This is not feasible. Therefore, energy-efficient communication solutions are a real challenge.

In [51], Popli et al. (2019) presented a comprehensive survey of energy-saving solutions for IoT systems based on NB-IoT technology. The survey concluded that NB-IoT technology would be an essential technology to realize green IoT networks in the future. In [52], Ding et al. (2019) presented an optimal scheduling solution based on the multiobjective fuzzy algorithm to save energy for IoT networks. In [53], Al-Kadhim et al. (2019) presented a reliable and saving energy data transmission solution for cloud-based IoT systems. The figures demonstrate that the proposed solution reduced energy consumption by 57% and improved reliability by 60% compared to the traditional solution.

In our opinion, energy efficiency can be considered based on some of the solutions as follows:

(i) *Communication technology-based*: integration of smart, flexibly, and low-power communication technologies such as NB-IoT and ZigBee. In [17], the authors presented a survey of the energy harvesting communication technology for autonomously power IoT devices. This technology promises green energy in the future

(ii) *Trade-off based*: In reality, performance and energy-saving have an antagonistic relationship. Therefore, a smart, flexible trade-off solution should be considered. In [54], Couso et al. (2018) proposed a trade-off solution for inverters to balance energy saving and performance for IoT-based smart grid applications

(iii) *Cloud-based IoT networks*: cloud will continue to be the backhaul infrastructure for IoT applications due to its robust storage, computing, and processing ability. However, cloud services have a high response time due to the edge computing solutions that are proposed. Consequently, an intelligent offload schema to optimal resource allocation between cloud and edge servers should be considered. In [55], Aljanabi et al. (2021) proposed a hybrid fog-cloud offloading schema to optimal performance and energy for IoT applications

4. Conclusion

In this study, we introduced the vision, architecture, wireless communication technologies, and research timelines of IoT in 5G. Based on the analysis of the core components for IoT in 5G, we conducted a short survey of low power communication technologies for IoT in 5G. The survey results showed that the Internet of Things would be the future of humanities, where all things such as software, systems, and people are connected through the Internet. The advent of IoT in 5G led to the formation of a series of applications serving humanity, such as smart homes, smart cities, smart agriculture, smart factories, green energy, and IoT systems. Besides, we have provided a full picture of promising communication technologies for IoT in 5G such as SigFox, LoRa, Wi-Fi, and LoRaWAN. These solutions are suitable for the operating characteristics of IoT networks such as large coverage areas, high energy efficiency, and low energy consumption level, which support a large number of IoT devices.

Moreover, the survey results also point out some challenges of communication technologies for IoT in 5G, including (1) privacy and security and (2) saving energy. In our opinion, the security and saving energy problems of communication technologies will continue to be exciting research topics in the future and receive attention from both academic research and industry. We hope that this study will play an important role as a guide for future research on communication technologies for IoT applications in 5G.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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