Chapter 9
Security Services for Wireless 5G Internet of Things (IoT) Systems

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Abstract The Internet of Things (IoT) is an emerging field that has evolved in recent past years and tends to have a major effect on our lives in the coming future. The development of communication techniques is very rapid and tends to achieve many innovative results. With the invention of 5th Generation mobile networks, i.e., 5G, it is becoming an exciting and challenging topic of interest in the field of wireless communication. 5G networks have the ability to connect millions or billions of nodes without affecting the quality of throughput and latency. The 5G technology can develop a truly digital society in which every device may be connected through the Internet. IoT is an emerging technology in which everything can be connected and communicated via the Internet, the term everything may include computing devices, humans, software, platforms, and solutions. The development of this technology leads to the advent of a number of solutions that are helpful for humankind, for example, smart retailing creation of smart cities, smart farming, intelligent transport systems, smart eco-systems, etc. While IoT is a revolutionary technology in the progression of the Internet, it still has some significant challenges for implementation like ensuring security, performance issues, quality of support and saving of energy, etc. Furthermore, the paper elaborates on the motivation of combining two

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technology together named IoT and 5G for better communication. Additionally, the paper illustrates the basic architecture of IoT enabling 5G and discussed various solutions to provide communication. Moreover, the paper also discussed the various challenges and research gaps of 5G-IoT technology.

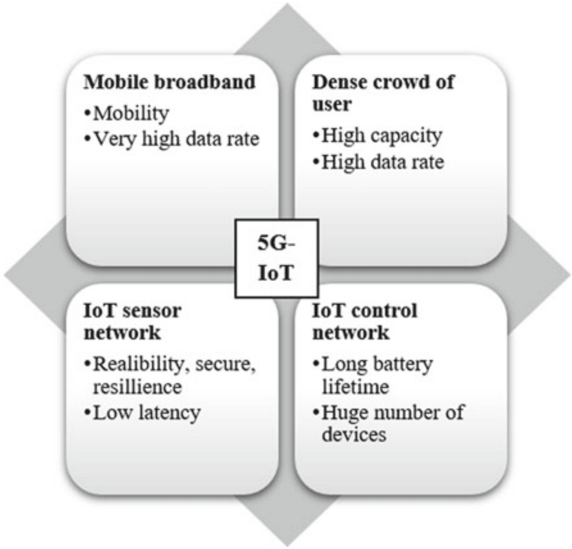
Keywords 5G · Internet of Things · Security · Communication · Devices · Data · Network · Layer · Challenges · Performance · Application

Introduction

The history of mobile communication systems' developments aims at meeting the requirements of humanity. With the passing of time, data rates of mobile communication have been improved and achieved great results compared to previous ones. Generations of mobile communications have progressed through five stages, i.e., from 1 Generation (1G) to the 5 Generation (5G) which is the current generation (Zhang et al. 2019). The generations between 1 to 3G have sequentially evolved on the basis of service qualities and speed factors. In the early stages of the year 2000, the concept of 4G was invented and it was the first communication generation that was totally built on the top of the IP packet switching technique (Liyanage et al. 2018). As the implementation of 4G technology improved over the years, the advantages of previous times started to convert into drawbacks. Currently, the 4G network's speed has turned out to be very low with respect to high latency (Maier and Reisslein 2019). A present time, kinds of solutions are needed which may connect at the data rates up to Gbps. In this sequence, the invention of the next-generation network, i.e., 5G in the duration of the initial 2021s, affected the whole digital world. Particularly, with the advent of the 5G concept, a new area of research has been generated, called as Internet of Things (IoT) (Bonfim et al. 2019). IoT technology can be defined as an integrated solution involving innovative technologies, allowing to connect together the people, platforms, software, services, devices, etc. via the Internet (Kitanov et al. 2021). According to a study by Cisco, by the year 2035, 1000 billion or more devices will be linked together through the Internet. Such devices, forming the network of IoT will be having all the advanced modules of IoT for allowing and implementing the Device to Device (D2D) communications with one another. The applications of IoT may be implemented in almost all the dimensions of humanity such as smart grids, smart farming (Han et al. 2019), self-driven cars (Zhang 2019), healthcare industries (Sarraf 2019), smart homes, supply chain industries, and many more (Architecture 2019). Moreover, some of the main features of 5G technology enabled with IoT are shown in Fig. 9.1.

The history of the development of all network generations presents an important insight that every single generation is evolved for correcting and modifying the drawbacks of earlier generations and for incorporating some new concepts things that the past generations could not apply (Malik et al. 2019). In the early stages year 2020, the concept of IoT has been proposed parallelly with the advent of 5G communication. The prediction according to a study state that by the year 2020 almost 40 billion nodes

Fig. 9.1 Features of 5G-IoT



are connected as part of an IoT network (Gautam et al. 2019). A critical challenge of implementing efficient IoT is the requirement of transferring huge data volumes among devices, which derives the need of improving the already existing infrastructures. The IoT technology has transformed the ubiquitous computing by considering various sensors-based applications (Shahabuddin et al. 2018). A huge amount of activity has been noted in IoT-based products and also it is expected to grow in the coming years at a high rate, i.e., billion devices and almost 15 devices on an average per person by the year 2024 (Shafique et al. 2020). In the past research works, most of the issues of protocol-level or device level have been resolved and presently the recent trend involves working on the issues of integration of sensor-based systems and D2D communications. IoT is becoming a central part of 5G wireless communication systems as IoT is the integration of various computing and non-computing, it will form a major part of this 5G network (Chettri and Bera 2020). IoT like D2D communication with the integration of data analytics may drastically transform the framework of many industries. With the rise of cloud computing technology inclusive of fog computing and the generation of intelligent devices, there are much more chances for future innovations in the field of IoT (Wang et al. 2018a). These innovations are motivations for the researchers to study and analyze current research, develop new frameworks, and incorporate them into the new applications. There are also various challenges associated with implementing IoT with the integration of 5G technology (Wang et al. 2018b).

Machine to Machine (M2M) communication plays an important role in the emerging paradigm of IoT. The integration of IoT and 5G technology may be extended to design and develop robots, drones, actuators for distributed coordination, and also the low latency execution tasks (Huang et al. 2018). Though the research studies also show the various significant challenges of IoT with 5G networks, for example, performance enhancement, quality of service support, security and privacy concerns, etc. (Malik and Steganography, 2020). Various solutions related to protocols, routing algorithms, architecture, or spectrum have been suggested for solving the significant problems (Esfahani et al. 2019). Moreover, the key motivation of the study is as follows:

- The work familiarizes with the inspiration and ideas of implementing 5G technology in cooperation with IoT technology for providing better communication and connection between smart devices and sensors.
- The work illustrates the vision of the IoT in 5G, the work also described the basic architecture of IoT in collaboration with 5G technology.
- The work deliberates the inclusive survey on the various recent communication technologies for IoT in 5G, where various technologies are explained such as SigFox, LoRa, and ZigBee.
- The work discussed the various challenges or vulnerable issues as well as numerous research gaps and future research directions to enable this technology in other technologies to provide better communication.

The rest of the paper is organized as follows. Section "Inspiration and ideas for 5G based on IoT" elaborates on the details and motivation to enable the IoT with 5G technology for better communication and connection in smart cities. Moreover, section "Structure of IoT in co-operation with 5G" discussed the architecture of IoT in cooperation with 5G, where all the five layers are discussed in detail. Here a table has also explained the use of IoT sensors in different smart areas. Additionally, section "Current resolutions for communication for IoT in 5G" explains the recent resolutions for communication and connection for IoT-enabled 5G technology where BLE, SigFox, IEEE 802.15.4, LoRa, Wi-Fi, ZigBee, and NB-IoT are explained along with a differencing table. Furthermore, section "Challenges and Security Vulnerabilities" highlights some challenges and vulnerable concerns of 5G enabled IoT technology. Moreover, section "Future Research Directions" elaborates on the various research gaps in numerous technologies and future research directions in 5G-IoT. Finally, section "Conclusion" devotes itself to the conclusion of the whole study.

Inspiration and Ideas for 5G Based on IoT

By looking into different challenges associated with 5G integrated with IoT, there is a deep motivation of providing a thorough study on 5G wireless communication that enables IoT (Henry et al. 2020). Since a huge number of researchers and communication industries are involved in researching the field of 5G-IoT, thus it gives us a kind of motivation and encouragement for providing the latest research perspectives on IoT. The network and communication technologies are the base of investigation for providing new insightful direction on 5G-IoT (Yarali 2020). At present, security is the most important concern in IoT as it is prone to cybercrimes. Thus, IoT has huge opportunities and possibilities for research and it also covers all technologies of 5G relevant to IoT. 5G-IoT is an architecture containing five layers. For enabling effective communication among devices and resource sharing, a generalized network framework is to be developed in 5G-IoT. This kind of generalized network may be able to decrease the cost and the complexity (Bikos and Sklavos 2018). Moreover, the evaluation of 5G from 1G is shown in Fig. 9.2 where IoT is enabled from 4G onwards.

In the current era of technology and advancements, the Internet is a vital component as communication between any devices or machines can only be established through it without any interruption from humans. 5G IoT is an immense technology that is implemented over critical communications and complex network technologies for example mm-wave technology, 5G New Radio (NR), Multiple Inputs Multiple Outputs (MIMO), etc. (Slamnik-Kriještorac et al. 2020). 5G technology runs at a very fast speed in comparison to the existing technologies and also comparatively huge number of devices can be connected within a network and reliable communication can be established (3GPP 2018).

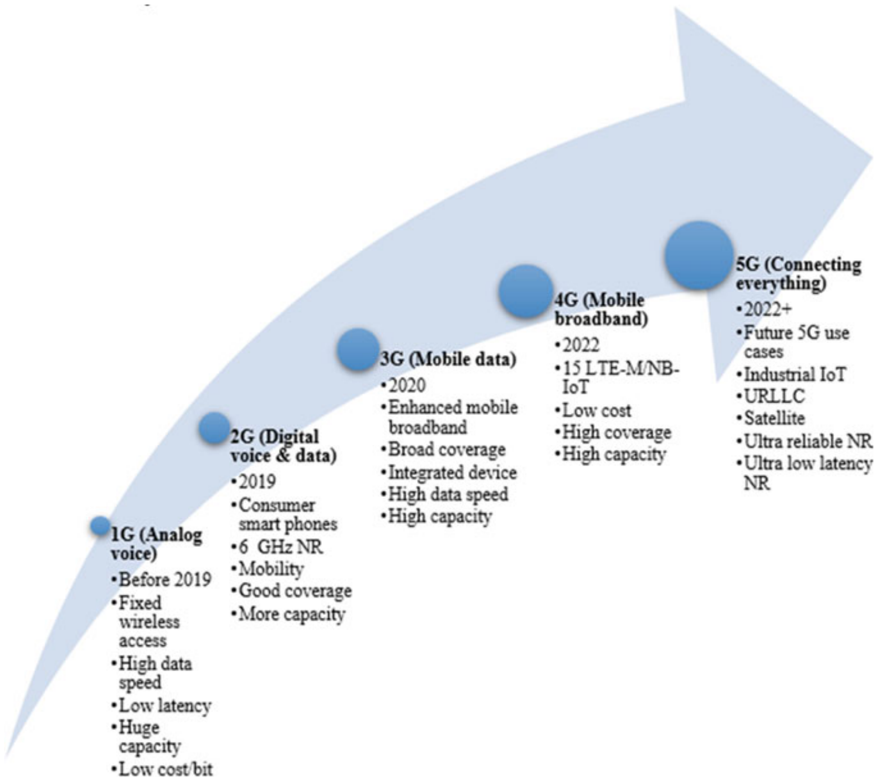


Fig. 9.2 Evaluation of 5G-IoT

Structure of IoT in Cooperation with 5G

IoT integrated with 5G technology is primarily implemented on of five-layered architecture. It includes the tasks of data collection, data processing, data analysis, and information sharing among various devices and communication links. In this type of architecture, the smart sensors remain connected through the gateway to the low-powered networks like Low-Power Wide Area Network (LPWAN), LoRa, NB-IoT, or SigFox that are used to establish long distanced communications (Le et al. 2021). The main task of this efficient gateway is to collect data from all the devices connected and transmit this information to base stations through the 5G communication links. By the use of 5G NR technologies with MM wave communication and effective numerology selection, the communication links of 5G technology can be designed. Furthermore, the 5G cellular base station processes the IoT signals that involve the MIMO antenna with the added capacity of spatial multiplexing and beam creation (Garro et al. 2020). The MM wave communication technology enables us to transfer the radio signals on higher frequencies, i.e., more than 6 GHz. There are numerous applications that can be implemented through 5G NR technologies (Kumar et al. 2019). Furthermore, the basic architecture of IoT in cooperation with 5G is shown in Fig. 9.3.

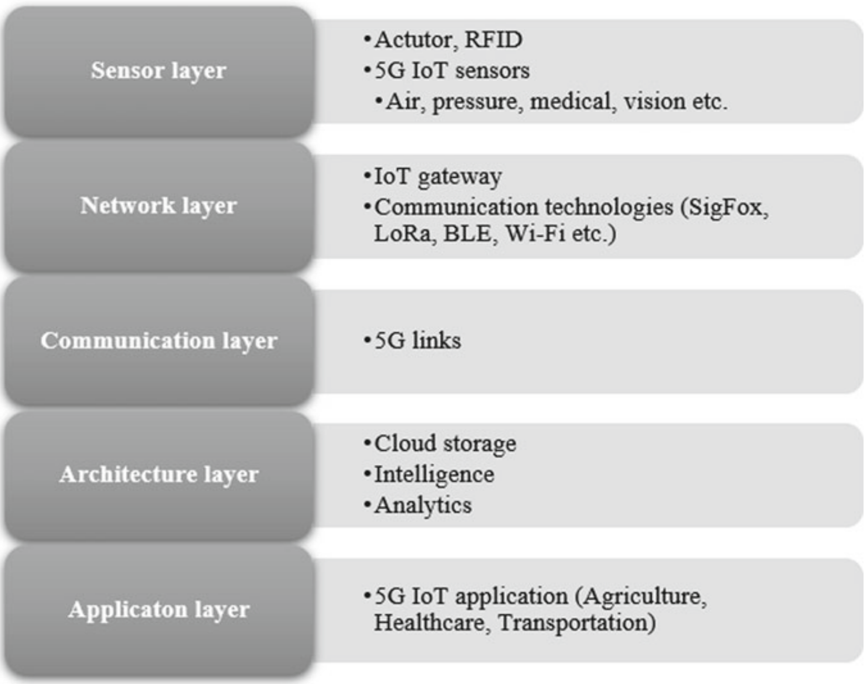


Fig. 9.3 Architecture of 5G-IoT

Sensor Layer

Sensors and other data collection devices create the first layer of the architecture. This sensor layer can be considered as a physical layer that includes devices, sensors, and actuators, and connects to the next layer, i.e., network layer. The present era is a technological era and utilization of the technology is everywhere. With the progression of electronic devices, semiconductor manufacturing industries, and automation solutions, the utilization of smart sensors is growing. the combination of sensors and integrated computing resources is called smart sensors. The smart sensors are able to communicate in a two-way manner between the network layer and sensors and analyze data to make useful decisions (https://www.5gradar.com/features/5g-security-5g-networks-contain-security-flaws-from-day-one). In an IoT architecture, the first layer accomplishes Machine Type Communication (MTC) and connects with the upper layer, i.e., network layer. The new smart sensors are more advantageous than the old conventional sensors like Smart protocols for establishing communication between devices and sensors, reduced communication through cables, easy to set up and maintain, flexible connectivity, reduced cost and less power solution, highly reliable, and effective performance (Anamalamudi et al. 2018). Some of the famous sensors based on 5G-IoT, which are used in different scenarios of IoT are shown in Table 9.1.

Network Layer

The second layer of IoT architecture is the network layer which comprises LPWAN like Sigfox, LoRa alliance, NB-IoT, ZigBee, etc. In 5G communication technology, the main task of the network layer is to deliver long-range and low-power connectivity for applications of IoT. A various number of connections may be established for achieving huge and complex connectivity by utilizing LPWAN. LPWAN is the technology that is mostly used for IoT applications as it provides a wide range of coverage areas, increased energy efficacy, less power consumption, and higher data transfer rates (Adame et al. 2019).

Communication Layer

The communication layer may be considered the support system of the architecture of IoT because its main task is of transferring all the information over all the layers. The Radio Access Technology (RAT) is used in the communication layer for 5G-IoT applications. 5G NR technology is an effort of 3GPP for developing a new standard for the wireless communication technologies of the next generations (Dutta and Hammad 2020). 5G NR technology is standardized as per the releases 15 and 16

Table 9.1 IoT sensors used in various applications

Application-based on IoT (Le et al. 2021; Garro et al. 2020; Kumar et al. 2019; https://www.5gradar.com/features/5g-security-5g-networks-contain-security-flaws-from-day-one; Anamalamudi et al. 2018; Adame et al. 2019; Dutta and Hammad 2020; Salem et al. 2022; Fang et al. 2018; Malik and Bhushan 2022; Frustaci et al. 2018)	Sensor-based on 5G-IoT
E-healthcare	X-Ray, E-wearable, Temperature, Pressure, SpO2, Ultrasound, ECG, EEG, BP, Pulse rate, etc
Public security	Location sensor radars, chemical operations, temperature observation, light monitoring, gyroscope
Smart industries	Proximity sensor, air quality sensor, fiber optic sensor, smoke sensor
Environment	Humidity, temperature, light, energy, harmful rays, chemical, pollution
Smart homes	Temperature, electronics device operators, LPG monitoring, robotics
Smart transportation	Traffic sensor, proximity, smart parking, position sensor, prior accident sensor, automatic driving sensor
E-study	3D presentation, robotic devices, sensor-based labs

of 3GPP. 5G NR technology is a subpart of RAT that has a composition of 5G NR and Long-Term Evolution (LTE) technology. There are two operational categories of 5G NR technology named 6 GHz and millimeter wave (mm-wave) range. Various intricate technologies such as NR support IoT with the inclusion of massive MIMO technology, waveforms, and frame structure. Radio access offers the complexities and opportunities, both, in the structure of Radio Access Network (RAN) specifically in IoT platforms like smart farming, smart home, critical services, smart factories, health care applications, and many more. 5G NR technology not only eases the market prospects for small base stations and small cells like picocells or femtocells but also facilitates the smart sensors for various kinds of IoT applications (Salem et al. 2022).

Architecture Layer

It is one of the layers of the IoT framework in which the architectures are included such as Big Data Analytics (BDA), cloud computing technology, etc. The cloud computing technology is mostly considered for 5G-IoT, as it is one of the trending technologies of IoT, and is mainly related to the Information Technology (IT) solutions. The system programming may also be embedded in it. The architecture of cloud technology is deployed with devices like a smartphone, Personal Computers (PC), host machines, and laptops. The integration of cloud technology with IoT architecture provides ubiquitous services which can be distributed to the clients with increased efficacy and less service management. Thus, IoT is a technology that is implemented with Big Data (BD), and data management is done by cloud computing technology. It is a kind of interface where all the services such as storage, data servers, authentication and authorization processes, the user interface for registration and login, are made available through the cloud (Fang et al. 2018). The cloud computing technology is categorized into three models which are as follows.

- **Infrastructure as a Service (I-a-a-S)**—This service is also called hardware as a service. This kind of service removes the need of installing any kind of hardware at our ends like server, storage, or computing resources. This service virtually provides all the services related to the infrastructure that is used to be present at data centers traditionally like network hardware, storage, maintenance, privacy, backup and recovery services, security services, and many more.
- **Platform as a Service (P-a-a-S)**—This kind of service provides hardware and software services virtually that are required for developing an application. The service may involve interfaces, development environments, and databases for maintaining data. Embedded systems that involve programming interfaces can also be implemented through this service. P-a-a-s frees the developers from the responsibility of installing and managing software or hardware services and enable them to focus on the application development only. The service provider maintains the services and resources.
- **Software as Service (S-a-a-S)**—S-a-a-S is a kind of software distribution service that works on the accomplishment of clients' demands. In this configuration, there is no need to install any software physically on the system but services related to the software can be provided to the clients according to their requirements. Also, the update or addition of new services in the software is installed automatically without any intervention from clients (Malik and Bhushan 2022).

Application Layer

The application layer works as an interface for integrating the network devices with network configurations. It provides integration of all the devices and information to the network or Internet. 5G MTC offers a large variety of services and applications. In future advanced technologies of wireless networks and communication, machines, and devices will be able to communicate without any intervention from humans (Frustaci et al. 2018). Nowadays, there is a variety of applications that require high latency and speed, high data rates, and connectivity of multiple devices.

Current Resolutions for Communication for IoT in 5G

With the advancement of semiconductor industries, electronics devices, and automation solutions, there is a rise in the development of communication solutions for 5G-IoT. These solutions are more reliable, smarter, have high data rates, are robust, and are energy efficient. So as an outcome, various communication technologies having low-power configurations are proposed for the 5G IoT, for example, LoRa, SigFox. The research studies state that low-power technologies have some unique characteristics like large coverage area, low-power consumption, higher data rates, energy efficient, etc., that are 5G-IoT. The following sections contain a discussion about the currently developed communication solutions for 5G-IoT (Wang et al. 2019).

Bluetooth Low Energy (BLE)

Bluetooth communication is generally implemented on laptops, PCs, cars, keyboards, wireless mouses, and earphones. This particular protocol is implemented on a Personal Area Network (PAN) and is able to establish communication between the devices over a short range of distances, i.e., almost 10 m. On the other hand, a modified protocol is required to be integrated into IoT as there is a need of decreasing power consumption to be able the execution with very short-sized batteries. Special Interest Group (SIG) of Bluetooth technology has inherited BLE technology while launching Bluetooth 4.0 version for identifying the market scenario (Chen et al. 2018). The BLE standard is designed with the ability to transfer small data packets periodically unlike the traditional Bluetooth technology. The key variation between the traditional Bluetooth technology and the new BLE technology is visible in the Physical (PHY) layer. The standard Bluetooth technology offers 79 channels containing 1 MHz bandwidth whereas the new BLE standard offers 40 channels from which 37 are data channels and the remaining 3 are advertising channels with 2 MHz bandwidth. In both the standards, the Radio Frequency (RF) is classified into two categories, i.e., data RF channels and advertising RF channels. In the first category, data channels are used for transferring data among the Bluetooth linked devices whereas the second category of a channel is utilized for connection, streaming, and device acquisition. Both kinds of channels are activated on an unregistered Industrial, Scientific, and Medical (ISM) frequency band of 2.4 GHz. In traditional Bluetooth standards, the process of switching varies from Gaussian Frequency Shift Keying (GFSK) to the Phase Shift Keying (PSK), i.e., 4-PSK and 8-PSK, whereas, in BLE standard, the GFSK optimization is done. The GFSK generates a less value of Peak-to-Average Power Ratio (PAPR), which infers lower power consumption due to the power amplification (Salimibeni et al. 2020).

SigFox

SigFox is a new technology, invented in the year 2010 with the purpose of connecting low-powered components or devices like smartwatches, meters of electricity, regulators, etc., which are required to be operated continuously at a very low rate of data. SigFox utilizes the RF band of ISM. It operates on a frequency of 868 MHz in Europe and at 902 MHz frequency in the US with 100 MHz channel bandwidth. SigFox signals can be transmitted easily through dense objects. These are called ultra-narrow band signals that provide low energy consumption. It is also called LPWAN technology due to the low power and energy requirements implemented in a single-hop star topology. SigFox technology is utilized for covering huge areas and reaching underground devices. The cells of SigFox provide a coverage range of about 30–50 km in less crowded areas and about 20–40 km in crowded areas like urban areas. Thus, conclusively, SigFox is developed for providing a Wide Area Network (WAN) with low consumption of power. At present, around 72 countries have been covered by the SigFox IoT system having a population of almost 1.4 billion (Ikpehai et al. 2019).

There are various applications as described in this section that is built on the top of SigFox communication. Mazhar et al. (2021) have developed an independent SigFox sensor node that is capable of collecting data from the sensors and passing data to the cloud platform for implementing smart agricultural applications. For enhancing the system, the sensors were designed in such a way, so as to consume solar energy. The experimental analysis states that the system enables transmitting data every five minutes even in cloudy conditions. Mroue et al. (2018) work on the analysis of the SigFox performance under various scales and density situations of IoT sensors. By the analysis, it is shown that approximately, a maximum of 100 sensors are able to transmit data at the same time moment. The outcomes show that, with the increasing number of sensors above 100, the performance of the network may be reduced. This particular study also presents solutions for the performance improvement of high-density sensors in SigFox. Lavric et al. (2019) developed an independent Sigfox-sensor-node which is able to transmit the sensor data to the cloud server directly. The solar cell is used for providing power backup and it is capable of transferring data in every 5 min in the cloudy weather at a data rate of around

5000 lx. This much of high data transmission rate has not been recorded till now for a completely autonomous setup. For the actual implementation, two sensor nodes were placed at the vineyard for collecting atmospheric parameters.

IEEE 802.15.4

IEEE 802.15.4 standard involves the specifications for Medium Access Control (MAC) and PHY layer. The PHY operates in various ISM groups which permit it to the region of operation. The worldwide standard band capacity is 2.4 GHz but there are other bands of data rates also exist such as 915 MHz in North America. IEEE 802.15.4 standard was intended to be developed for PAN. It was primarily used for the applications of the organizations such as ecological, agricultural, and engineering. If compared to the IEEE 802.11 standard, IEEE 802.15.4 is not prominent for higher rates of data, and also it does not emphasize on linking of the devices. Thus, this provides lower data rates for wireless communication for portable, fixed, or less battery-moving devices. Zigbee can be an example that effectively used IEEE 802.15.4 standard. The major advantage of Zigbee as compared to others is that it is proficient in working with multi-hop structures and can also perform well under network failures (Musaddiq et al. 2021). There are seven different categories of working modes proposed in the IEEE 802.15.4 standard. The primary methods for lower energy consumption from the IoT point of view are Offset Quadrature Phase Shift Keying with Direct Sequence Spread Spectrum (OQPSK-DSSS), Differential Quadrature Phase Shift keying variation with Chirp Spread Spectrum (DQPSK-CSS), and Gaussian Frequency Shift Keying (GFSK) with non-virtual distribution (Aboubakar et al. 2020).

LoRa

The LoRa is an emergent and one of the most important LPWAN communiqué technology. It has the capability to provide connectivity to the energy-constrained devices that are distributed over a wide area and that too at lower costs. The LoRa technology makes use of the LPWAN modulation process and unlicensed bands of frequency such as 433 and 868 MHz in the Europe region, 915 MHz in North America and Australia region, and 923 MHz for the Asia region. LoRa provides transmissions over a wide range with low consumption of power. The LoRa technology is operated on PHY and the protocols like Long Range Wide Area Network (LoRaWAN) operate over the network layer. It may achieve the data rates between 0.3 and 27 kbps (around) dependent on the distribution factor. Though, as per the studies, implementing a flexible LoRa network with a cost-effective feature is still a significant challenge (Leonardi et al. 2019).

Ma et al. (2021) proposed and developed an open-access LoRa framework for IoT. This particular development process involves the design framework and implementation of hardware for the LoRa gateway which uses open-source codes of LoRa available on GitHub. The LoRa server can be improved by the utilization of the messages system to create interaction among different modules for scalability and flexibility enhancement. The outcomes of this experiment show that there is a significant improvement in the performance of the LoRa network when compared to the traditional LoRa. Lee et al. (2018) analyzed the LoRa mesh network for examining its ability to be applied in urban areas. For this analysis work, 19 LoRa mesh nodes were installed in a range of 800 × 600 m in the campus area of a university and a gateway is also installed which performed the data collection at the time interval of 1 min. The results of the experiment disclosed that the average packet delivery ratio achieved from the mesh LoRa framework is almost 93.19%, while the star topology of LoRa was able to achieve only 67.9% delivery ratio under the similar circumstances. The LoRa is considered to be the most effective out of all the LPWAN technologies. It is capable of establishing robust communications in IoT applications over large distances with very low-power consumption. This technology is also promising from the industrial perspective of IoT. Though the LoRa framework also has a limitation in that it does not provide support for data flows in real time. For overcoming this limitation, Senewe et al. (Senewe and Suryanegara 2020) designed a new strategy related to media access, called Real-Time LoRa (RT-LoRa), which aims to provide real-time support for IoT applications based on LoRa. The experimental outputs state that RT-LoRa is capable of supporting real-time data flows.

Wi-Fi

Wi-Fi technology is a very well-acknowledged and well-used technology of wireless communication based on the IEEE 802.11 standard. It is generally used for accessing the Internet within the range of 100 m. Its operational frequency band is 2.4–5 GHz. Since Wi-Fi is appropriate for communication within a short range that's why it is the right solution for establishing communication in IoT networks. Jiang et al. (2021) proposed a solution for smart homes IoT applications based on queue management where access points are linked together through Wi-Fi. The main goal of this work was to propose an admission control mechanism at the access point of Wi-Fi for reducing the time of response. The results of the experiment proved that the new system based on Wi-Fi is extra reliable and stable than the earlier smart home IoT applications. Qi et al. (2020) invented a new solution based on WIOTAP to propose an energy-saving communication for Wi-Fi-based IoT systems. This solution works on an intelligent access point of Wi-Fi. It presented a mechanism for reducing contention of downlink channel access and delay in queuing process of stations, called downlink packet scheduling mechanism. The outputs of the experiment stated that the current system is an improved one from the old one. Thus, the consumption of energy was improved by 38% whereas delay was enhanced by 41%.

The most crucial challenge of IoT is tracking and locating in real-time scenarios. Systems or applications based on Global Positioning System (GPS) are very well recognized for the outside surroundings and it is not appropriate for interior scenarios. Pokhrel et al. (2020) projected a new Wi-Fi signal-based IoT solution to locate and track interior environments. The work uses a type of message which is built upon the 802.11–REVmc2 standard of Wi-Fi. To enhance the accuracy and capability of the positioning system, the time of roundtrip and signal strength are analyzed. The results of the experimental setup have presented that the current system improvised the performance and attained the positional accuracy average of 1.43 m for 0.19 s update time for interior scenarios.

ZigBee

ZigBee is a technology of wireless communication that is based on the IEEE 802.15.4 standard and is operational in the ISM RF bands. It was designed for providing low-power and low-cost wireless communication for IoT infrastructure. ZigBee technology is advantageous over other communication techniques related to IoT networks due to its reduced costs, simplicity of implementation, and flexibility feature. The ZigBee is able to transmit data over a distance of 100 m at a data rate of 250 kbps, depending upon environmental and power attributes. ZigBee technology is typically applicable in the scenarios of lower data rate networks, long-term battery life, and short-range communication like smart homes, healthcare devices, manufacturing equipment control, etc. Franco et al. (Franco de Almeida and Leonel Mendes 2018) developed a MIMO-based ZigBee receiver for controlling jamming attacks in IoT networks. This work also proposed a learning method to reduce unfamiliar interference. The results of the proposed experiment confirmed that the developed system may provide the jamming mitigation capacity of 26.7 dB on an average in comparison to the previous version of ZigBee receiver.

Yu et al. (2019) proposed a time-stamp-based security framework for handling replay attacks for ZigBee. This proposed solution significantly improvises the consumption of energy. Also, for enhancement of feasibility, this framework makes use of powered devices for providing energy to the devices that are power constrained along with the present time-stamp. The framework is designed in such a way that it is appropriate for all the ZigBee systems. The experimental setup significantly enhances the handling of replay attacks in IoT networks based on ZigBee. Karie et al. (2021) proposed a design of smart sensors by combining two different communication modules, i.e., LoRa and ZigBee for measuring the factors like humidity and temperature and humidity for the IoT applications. By using transceiver modules of LoRa or ZigBee, the sensor data is transferred to the central receiver. The real-world design and experimental statistics represent the advantages of high range and low-power communication frameworks for the applications of IoT.

NarrowBand IoT

NarrowBand IoT (NB-IoT) is a new radio technology based on LPWAN which is invented by the 3GPP group for supporting a huge number of connections, wide coverage area, lower cost, and low-power consumption in 5G IoT (Chen et al. 2019). It is an emerging and evolving communication technique for 5G IoT (Migabo et al. 2018). The main focus of NB-IoT is indoor area coverage, less expense, extended battery life, and massive connections (Loulou et al. 2020; Ghazali et al. 2021). The utilized bandwidth is narrow, i.e., 200 kHz. For downlink communication, the OFDM modulation technique is used and SC-FDMA is applied for the uplink communication. Thanh et al. (2019) proposed an open-source prototype of an NB-IoT network for 5G IoT applications. This experiment represents a process of utilizing the already existing module of commercial NB-IoT for transmitting the sensor data through open-source NB-IoT. Cao et al. (2020) performed the performance evaluation and modified the NB-IoT protocol for improvement in 5G IoT. The main motive of this work is to evaluate the "delay metric" by using the stochastic network and to improvise the NB-IoT protocol by improving the k means clustering algorithm to categorize the devices and perform a priority-driven scheduling strategy. The outcomes of the experiment showed that the proposed scheduling method for uplink traffic has improved the performance over the already existing scheduling schema. Goyal et al. (2021) proposed a methodology for designing the PHY of the NB-IoT device. The main goal of this work is to present the features, uplink, and downlink scheduling of physical channels present at the base station and devices of the user end for helping users to know the specifications of 3GPP without much reading. Hence, a summarized view of the above-discussed current solution for communication in 5G-IoT is shown in Table 9.2.

Challenges and Security Vulnerabilities

This particular study highlights the various innovative contributions of 5G IoT in a variety of fields for serving humanity. Low power technologies are the main support system for implementing IoT applications commercially. These applications may be related to various domains like environmental conditions, smart cities, homes, buildings, and smart farming (Nurlan et al. 2022). The communication technologies, increasingly applied in IoT applications have various characteristics like low-power consumption, wide-area coverage, higher data rates, wide frequency bands, etc. which make these technologies suitable to be applied in IoT architecture. Examples of these technologies include BLE, ZigBee, IEEE 802.15.4, SigFox, LoRa, and many more. The goal of these communication services is to establish connectivity in 5G IoT applications. Although these technologies are useful, there are a variety of challenges related to implementation as it connects a billion IoT devices. The

Table 9.2 Difference between current solutions for communication in 5G-IoT

Technology (Salimibeni et al. 2020; Ikpehai, et al. 2019; Mazhar et al. 2021; Mroue et al. 2018; Lavric et al. 2019; Musaddiq et al. 2021; Aboubakar et al. 2020; Leonardi et al. 2019; Ma et al. 2021; Lee and Ke 2018; Senewe and Suryanegara 2020; Jiang, et al. 2021; Qi et al. 2020; Pokhrel et al. 2020; Franco de Almeida and Leonel Mendes 2018; Yu et al. July 2019; Karie et al. 2021; Chen et al. 2019; Migabo et al. 2018; Loulou, et al. 2020; Ghazali et al. 2021; Thanh et al. 2019; Cao, et al. 2020; Goyal et al. 2021)	BLE	SigFox	IEEE 802.15.4	LoRa	Wi-Fi	ZigBee	NB-IoT
Range	100 m	Many Kms	100 m	2–5 km	Many Kms	< 1 km	1–10 km
Bandwidth	1–10 Mb/s	250/500 kHz	2.4 GHz, 2 MHz	100 Hz	20/40 MHz	2 MHz	200 kHz
Standardization	IEEE 802.15.1 alliance	Collaboration of ETSI	LR-WPAN	LoRa alliance	IEEE 802.11 alliance	ZigBee alliance	3GPP
Cost	Low	Medium	Low	Medium	Low	Medium	Low
Frequency band	2.4 GHz	<1 GHz	2.4 GHz	<1 GHz	<1, 2.4, 5 GHz	902–928 MHz, 2.4 GHz	700.800, 900 MHz
Maximum data rate	1 Mb/s	100 b/s	0.252 Mb/s	18 b/s-37.5 kb/s	1–54 Mb/s	250 kb/s	200 kb/s
Power	Low	Low	Low	Low	Medium	Low	Low
Spectrum strategy	Wideband	Ultra narrow band	Wideband	Wideband	Wideband	Wideband	Wideband

(continued)

Table 9.2 (continued)

Technology (Salimibeni et al. 2020; Ikpehai, et al. 2019; Mazhar et al. 2021; Mroue et al. 2018; Lavric et al. 2019; Musaddiq et al. 2021; Aboubakar et al. 2020; Leonardi et al. 2019; Ma et al. 2021; Lee and Ke 2018; Senewe and Suryanegara 2020; Jiang, et al. 2021; Qi et al. 2020; Pokhrel et al. 2020; Franco de Almeida and Leonel Mendes 2018; Yu et al. July 2019; Karie et al. 2021; Chen et al. 2019; Migabo et al. 2018; Loulou, et al. 2020; Ghazali et al. 2021; Thanh et al. 2019; Cao, et al. 2020; Goyal et al. 2021)	BLE	SigFox	IEEE 802.15.4	LoRa	Wi-Fi	ZigBee	NB-IoT
Modulation	GFSK	DBPSK	O-QPSK, CCK/DSSS	LoRa	256-QAM	BPSK, QPSK	QPSK
Sensitivity	−95 dBm	−126 dBm	−97 dBm	−149 dBm	−95 dBm	−85 dBm	−141 dBm
1-Hop latency	3 ms	2 s	1.5/1./20 ms	500 ms	NA	140 ms	1 Mb/s

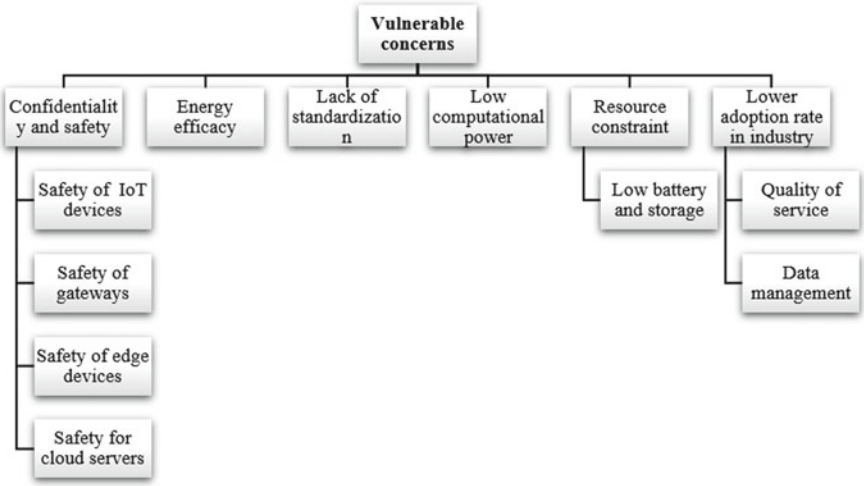


Fig. 9.4 Issues of 5G-IoT that need to be addressed

two key issues are related to energy efficiency and security (Ahmad et al. 2020). Additionally, Fig. 9.4 shows the various vulnerable concerns in 5G-IoT technology.

Confidentiality and Safety

The main aim of IoT is to establish connectivity between everything. The invention of IoT infrastructure has formed an open world in which everything is linked via the Internet. But there are always cons associated with pros. As everything is connected to the Internet, the nodes or devices are very much prone to security threats and attacks. Thus, security and privacy issues are the most crucial factors for promoting the development of IoT infrastructure to be implemented practically (Arora et al. 2020). The security attacks may be injected into multiple layers of IoT architecture.

- **Safety for IoT devices**: The devices included in IoT infrastructure are of low computing capacity and huge in numbers and are not appropriate for framing a robust and secure system. Therefore, the main focus of attackers is to exploit the weaknesses of the IoT devices.
- **Safety for gateway devices**: The gateway is a communication interface between the PHY devices and the higher layers. That's why it is called the central part of IoT infrastructure. The attacks like Denial of Service (DoS) or spoofing of data generally target the gateway device of IoT.
- **Safety for edge devices**: The technology of edge computing is a core part of the newly proposed solutions for reducing the response time of services in real-time IoT. Therefore, securing the edge servers from attacks is a key challenge.

- **Safety for cloud servers**: Cloud technology is a probable solution for storing and analyzing the vast volume of data generated from IoT devices. Thus, ensuring the security feature of cloud-based servers is also the main challenge (Malik et al. 2018).

Energy Efficacy

Though the applications of IoT are considered to be energy efficient, the energy consumption of their own is so much. It is assumed from the study results that as the 5G IoT applications are becoming widespread, the billions of IoT-connected devices will be operational and transmitting data endlessly at every moment. So as a consequence, there will be a massive amount of energy consumption and it will also increase with every passing moment. Therefore, implementing such solutions that are feasible and energy efficient is a major challenge (Atakora and Chenji 2018).

Future Research Directions

The need for 5G communication technology at present time is to deliver standards for establishing communication among a huge number of devices over a wide area for fulfilling the requirements of industrial as well as social applications related to IoT. For the successful implementation of such technology, it is vital to identify the technical and practical challenges along with ensuring the QoS (Generation Partnership Project (3GPP 2018). In particular, the section tries to represent some significant challenges related to 5G IoT and some ideas for future research, which are shown in Fig. 9.5.

Structure of Network Based on Big Data

The present structure of wireless communication networks is to facilitate data transmission and establish communication among the devices of the network. For accessing the key benefits of BD in the field of 5G IoT, the new solutions and frameworks considering the BD have to be proposed. This new framework is capable of accommodating a huge volume of data and integrating that BD into the network very efficiently. This novel solution focuses on ignoring the unexploited data and processing the desired information at a suitable location (Ijaz et al. 2018). Another feature of research related to big-data analytics is personalized networking. This new approach includes Service-Function Chain (SFC) or network partitioning which supports various services of BD by developing a service concerned networking on the top of the physical network. Further customization of network partitioning can

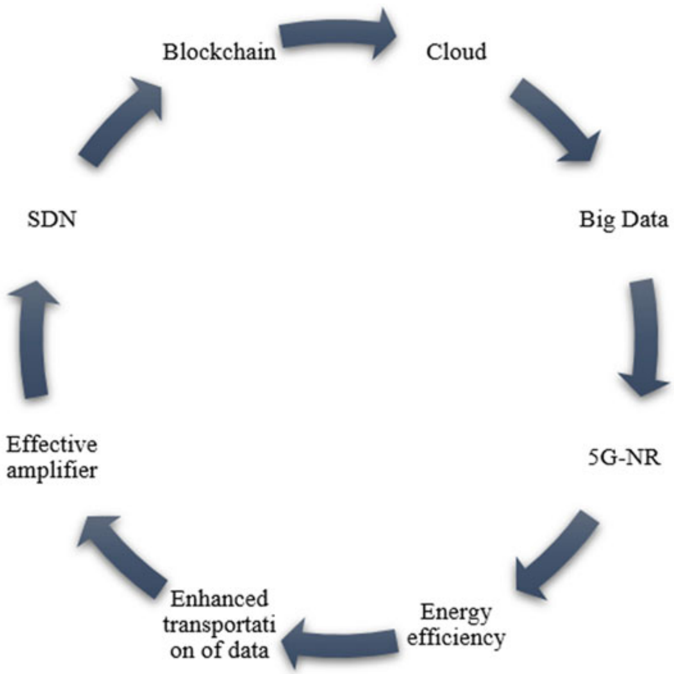


Fig. 9.5 Research gaps of 5G-IoT

be done according to the requirements of services. To make the most utilization of network resources, multiple partitioning or SFC should be used. In 5G technology, SFC should have the capability of identifying variations in the network status and service needs (Sharma et al. 2021).

5G New Radio (NR): A New Wave-Form Design Consideration

The selection of wave-form is the most crucial part of the design of 5G NR technology. The primary choice for designing LTE was OFDM but it is not appropriate for 5G wave-form due to its higher Inter-Channel Interference (ICI), increased Inter Symbol Interference (ISI), and higher PAPR. So, all these OFDM wave-form limitations can be taken as challenges for future research in 5G. The primary design characteristic of the new wave-form must be less latency (<1 ms) for enabling new services. The feature of low latency is useful for IoT applications and very less latency is utilized for enhanced Mobile Broadband (eMBB) and crucial communications such as automatic driving. Another aspect of designing a new wave is applying a cyclic prefix. It can be used in both modes, normal as well as extended. To design the wave-form, selection of numerology is considered and it uses dissimilar numeric values. By considering all mentioned aspects of the 5G wave-form, different kinds of the wave-form such as Filter Bank Multi-Carrier (FBMC) or Generalized Frequency Division Multiplexing (GFDM) can be generated (Khapre et al. 2020; Alfian et al. 2018).

Energy Efficacy

As per the thorough review studies, the key consideration to design and develop 5G wireless networks is energy consumption. As the 5G technology evolved, a billion devices are likely to be connected within a single network having various base stations in comparison to LTE networks. Thus, to accommodate such a huge number of devices, there is a need of proposing an energy-efficient solution. The first assumption for overcoming this problem may be to set up a small-cell base station. Such kind of base station is able to enhance the capacity in the areas of higher density. It is capable to improvise coverage area, battery life, and data rates by reducing the consumption of power. Energy efficacy may be attained through the framework as follows.

- Deployment and energy efficacy trade-off: It is important in achieving reduced consumption of energy and less cost in the proposed network.
- Spectrum and energy efficacy trade-off: It is utilized for balancing the consumption of energy.
- Bandwidth and power trade-off: For a target rate of transmission, it is utilized for balancing the bandwidth consumption.
- Delay power trade-off: Use of it is for balancing average service delay with respect to power consumption (Nie et al. 2020; Latif et al. 2019).

Interchange Between Communication, Gathering, and Computing

5G wireless communication is a kind of diverse communication. The tasks of collecting data and computing resources should be performed intelligently for supporting BD in a heterogeneous network of 5G-IoT. Thus, a balancing factor is important for communication, catching process, and resource computing. For reducing the cost of storage, the results of computation must be saved on a temporary basis. For providing optimal resources, the balance between the heterogeneous resources is essential. The 5G IoT technology has evolved with the vast volume of data resources. This data is gathered from various resources that generate data distribution in a non-uniform manner. Thus, for storing, retrieving, and analyzing this huge volume of data, the proposed solution is cooperative edge catching. For the processing of data, edge computing technology is needed (Escolar et al. 2021; Yang et al. 2020).

Design of Synchronized Multi-Band, and High-Power Effective Amplifier

The importance of a multi-band power amplifier is for reducing the cost and size of the base station in 5G-IoT. It is capable of supporting multi-band frequency signals concurrently which enables all the functions to execute at the same time (Failed 2020). The most capable amplifiers are concurrent and parallel single-band power amplifiers. In 5G NR, the MIMO and mmwave are used for communication at the base station. The linear RF power amplification is important for the consumption of energy at the base station. The application of a power amplifier is also helpful to reduce heat dissipation at the base station. Reduction in energy consumption of radio stations also tends to decrease the environmental input of RAT (Tikhvinskiy et al. 2020).

Conclusion

The most important vision of 5G-IoT technology is to establish communication among a various number of devices under a similar network. There is a lot of application based on 5G wireless communication such as smart farming smart homes, smart cars, smart city, and smart medical devices that led to the revolution in IoT. The implementation of such applications requires the establishment of huge connectivity at a higher speed under 5G wireless technology. On the basis of the analysis of essential components of 5G-IoT, this review study represents a brief discussion about power-constrained communication technologies. The IoT will be considered the new future for the world where everything will be linked together by the Internet like devices, software, people and systems, etc. The invention of 5G-IoT technology has developed a variety of applications like intelligent farming, smart cities, smart homes, smart healthcare devices, green energy systems, etc. This study has presented a complete overview of all the communication techniques of 5G-IoT that are characterized by huge coverage, increased energy efficacy, and low consumption of power. By concluding the current research work, the aspects related to energy consumption and security will be an interesting area of future research and will obtain attention from industry as well as a research perspective. Research in the field of 5G-IoT may be proven to be a social service in the development of a better world.

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