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Communication in IoT: Current Trends and Future Directions

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Abstract: *The advent of mobile gadgets has revolutionized our daily lives. They allow consumers to access information even in a mobile setting and deliver unrestricted information. Following ten years since the inception of this technology, we are now confronted with the forthcoming advancement that will revolutionize our everyday existence. The advent of the Internet of Things (IoT) will expand our communication capabilities beyond only mobile devices. Instead, it will encompass all entities that exist alongside us. This study will review and compare several wireless communication topologies in IoT which are classified according to operation area.*

Keywords: *IPv6, 6LoWPAN, ZigBee, BLE, Z-Wave, NFC, SigFox*

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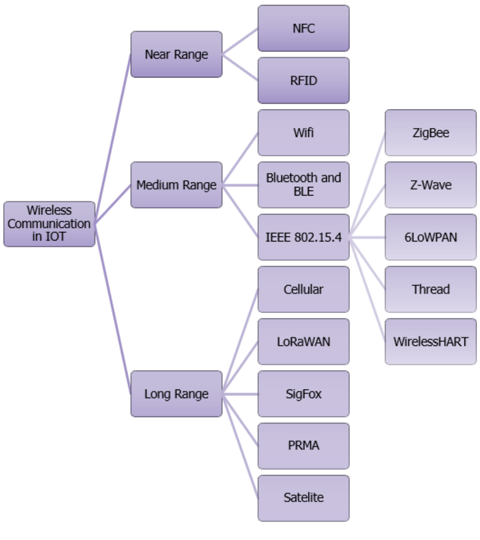
I. INTRODUCTION

The Internet of Things (IoT) is about to enter its golden era. It will enable things and even produced contents to interact with different mediums. The data obtained from each object will undergo customization to meet the specific requirements of users and may also be integrated with other data sources. The concept of IoT is straightforward; however, its potential is boundless, and its application has the ability to completely transform traditional technology. The system is built by integrating a network interface into objects, allowing them to communicate with each other and offer a range of services to consumers. As a result, every object will possess its own unique identifier, such as an Internet Protocol address (IP address) on the existing Internet, which enables it to connect and communicate with other objects inside the IoT networking environment. In contrast to the pre-IoT period, where users were limited to obtaining data solely from service providers, users now have the ability to directly access sensors and issue commands to actuators. This capacity will enable the utilization of data from IoT applications to offer a unique service to industry, academia, and even personal use [1], [2]. The IoT ecosystem comprises a vast array of intelligent devices, albeit with numerous limitations. Constraints such as limited processing capability, storage volume, short power life, and limited radio range are present. Thus, the installation of IoT need communication protocols that can effectively handle these circumstances.

Figure1. Classification of Wireless communication in IoT



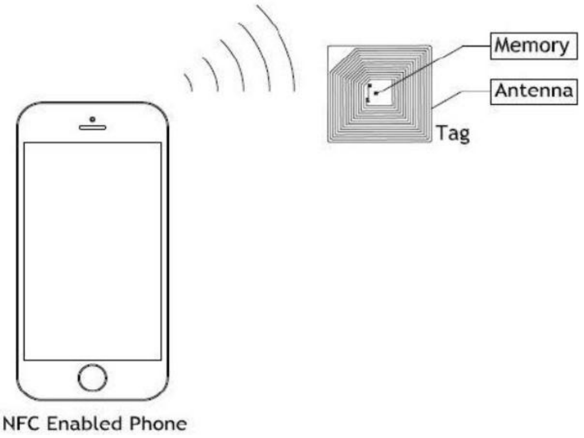
This study will also evaluate and contrast several IoT communication protocols (Fig. 1), providing readers with a comprehensive understanding of distinct IoT communication protocol visions and their specifications. The remainder of the paper will be structured as follows: Section II will outline various topologies used in Near range wireless communications. Section III will present various topologies for Medium range wireless communication. Section IV will provide a description of long-range wireless communication. Ultimately, the study's conclusion has been obtained for the final section.

II. NEAR RANGE WIRELESS COMMUNICATION

1.1 Near Field Communication (NFC)

Near Field Communication, a novel communication technology, is gaining popularity in mobile smartphones. In order for this technology to communicate, it requires two NFC compliant devices to be positioned in close range to one other, with a distance of less than 4cm. NFC runs at a frequency of 13.56 MHz and has the capability to send information at a maximum rate of 424 Kbits per second [3]. For NFC connectivity, a minimum of two devices is required. The first device is referred to as the initiator, which is an active device that initiates the communication process. On the other hand, the second device is known as the target and it replies to the requests made by the initiator. The target device can either be in an active or passive state. Communication initiates when the active device approaches the target and produces a magnetic field of 13.56 MHz, which then supplies power to the target device [4] (Fig. 2). NFC technology functions through the process of magnetic field induction and operates inside an unlicensed radio frequency range. The system incorporates an integrated energy source component. The target can be either an Radio Frequency Identification card, tag, or an NFC device, which provides a response to the initiator's request [5]. Touchbased and simple contact between the two gadgets is made possible by NFC, and the process of setting up communication with NFC takes only a few milliseconds. NFC technology is utilized for a range of uses including but not limited to the as follows: ticketing, payment, file sharing between phones, and so on.

Figure2. Radio Frequency Identification (RFID)



1.2 Radio Frequency Identification (RFID)

The Radio Frequency Identification (RFID) technology is a rapidly developing technology that finds applications in several fields. It belongs to the Automatic Identification and Data Capture (AIDC) family of technologies. This is the most efficient and dependable way of recognizing an object or entity. RFID comprises two primary components: the interrogator and the transponder. The Interrogator, also known as the RFID Reader, is responsible for transmitting and receiving signals, while the Transponder (tag) is attached to the object. In the RFID system, an RFID reader queries the RFID tags. This tag reader emits a radio frequency signal to communicate with the registered tags in the system. The reader also includes a receiver that catches and decodes the reply signal provided by the tags. The reply signal emitted by the tags indicates the informational content of the tags. An RFID tag typically comprises an antenna and a minuscule microprocessor [6]. RFID technology improves inventory management, supply chain management, healthcare, security, and access control across diverse industries. It enhances inventory management, minimizes inaccuracies and pilferage, and optimizes manufacturing operations. RFID technology also facilitates agriculture and livestock management, document management, wildlife conservation, and enhances consumer experiences. The uses of this technology encompass libraries, archives, animal conservation, and smart packaging.

III. MEDIUM RANGE WIRELESS COMMUNICATION

3.1. The IEEE 802.11a/b/g/n (Wifi)

Wi-Fi is a technology based on the IEEE 802.11 specifications that allows for wireless access to local area networks (LANs). It has become a foundational element in modern communication, especially for the burgeoning Internet of Things (IoT) ecosystem. Wi-Fi allows a myriad of devices, from smartphones and laptops to smart home gadgets and industrial sensors, to connect and communicate seamlessly. The Wi-Fi Alliance, an industry consortium, plays a vital role in this landscape by certifying products to ensure they meet established standards for interoperability, security, and performance, thus fostering a reliable and cohesive user experience across different brands and devices.

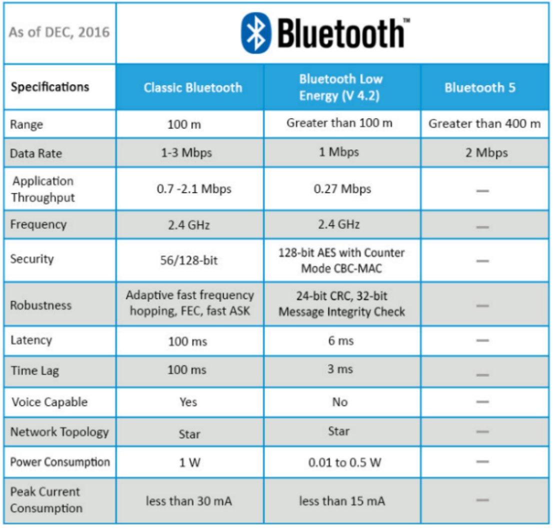
Among the Wi-Fi protocols, 802.11n stands out for its ability to deliver very high data throughputs, making it suitable for bandwidth-intensive applications such as video streaming and large file transfers. However, this high performance comes at the cost of increased power consumption, which can be a significant drawback for battery-powered IoT devices. To address this, many IoT devices prefer using 802.11b or 802.11g protocols. These standards offer a more balanced approach by providing sufficient data rates while conserving power, thereby extending the battery life of IoT devices [7].

The choice of Wi-Fi protocol is a critical consideration in the design and deployment of IoT solutions. While high throughput is desirable for applications requiring fast and large data transfers, power efficiency is paramount for devices that need to operate for extended periods on limited power sources. This balance between performance and power consumption ensures that IoT devices can deliver their intended functionality reliably and sustainably. Furthermore, the widespread adoption of Wi-Fi in IoT underscores the importance of ongoing advancements in Wi-Fi technology, which continue to drive innovation and enhance connectivity in an increasingly interconnected world.

3.2. Bluetooth and Bluetooth Low Energy (BLE)

Bluetooth technology and Bluetooth Low Energy (BLE) have become crucial for enabling wireless communication, yet they serve different needs and applications due to their distinct features. Initially developed for connecting wireless headsets to cellphones, traditional Bluetooth is now available to many devices such as keyboards, mouse, speakers, and automotive audio systems. It is recognized for its strong data transfer capabilities, providing greater data rates that are ideal for applications that need reliable and significant data streams, such as transmitting audio and transferring files. Nevertheless, enhanced performance is accompanied by increased power consumption, rendering it less suitable for applications that require prolonged battery operation [8]. Conversely, Bluetooth Low Energy, originally known as Wibree, was particularly created to overcome the power consumption constraints seen in traditional Bluetooth. BLE has been developed specifically for personal devices that prioritize long battery life, for example personal health monitors, activity monitors, smartwatches, and various Internet of Things devices. BLE provides reduced battery consumption by retaining a comparable communication range to classic Bluetooth while operating at lower data rates and shorter connection intervals. BLE is suitable for devices that deliver little, intermittent data, allowing them to work for long periods, up to years, on just one power source. [9].

Figure3. Bluetooth versions



As of DEC, 2016	Bluetooth™		
Specifications	Classic Bluetooth	Bluetooth Low Energy (V 4.2)	Bluetooth 5
Range	100 m	Greater than 100 m	Greater than 400 m
Data Rate	1-3 Mbps	1 Mbps	2 Mbps
Application Throughput	0.7 -2.1 Mbps	0.27 Mbps	—
Frequency	2.4 GHz	2.4 GHz	—
Security	56/128-bit	128-bit AES with Counter Mode CBC-MAC	—
Robustness	Adaptive fast frequency hopping, FEC, fast ASK	24-bit CRC, 32-bit Message Integrity Check	—
Latency	100 ms	6 ms	—
Time Lag	100 ms	3 ms	—
Voice Capable	Yes	No	—
Network Topology	Star	Star	—
Power Consumption	1 W	0.01 to 0.5 W	—
Peak Current Consumption	less than 30 mA	less than 15 mA	—

Both technologies typically have a maximum range of approximately 100 meters, however their usage contexts varies greatly. Traditional Bluetooth is suitable for continuous, highbandwidth processes, while BLE is more effective for devices that need temporary, low-bandwidth connection. Bluetooth and BLE are not in conflict with each other, but rather complement each other by addressing various aspects of wireless connectivity demands. Bluetooth remains successful in applications where performance is crucial, while BLE shines in settings where energy efficiency and battery life are of utmost importance.

3.3. IEEE 802.15.4

IEEE 802.15.4 is a standard for wireless personal area networks (WPANs) designed to facilitate low-power, lowdata-rate communication. It is the foundation for various communication protocols such as Z-Wave, Zigbee, 6LoWPAN, Thread, and WirelessHART. These protocols leverage the standard to provide efficient, reliable connectivity for applications like home automation, industrial control, and smart metering, prioritizing energy efficiency and extended battery life for connected devices.

3.3.1. Zigbee

Zigbee is a wireless communication technology that is based on the IEEE 802.15.4 standard. It is noted for its ability to consume low power and its strong networking capabilities. The capability to establish scalable and dependable mesh networks makes it highly suitable for a diverse array of applications across many industries [10]. Zigbee facilitates the smooth integration and management of intelligent devices like lighting, thermostats, and security systems in home automation, providing users with improved convenience and energy conservation. Zigbee enables effective monitoringand management of equipment in industrial environments, leading to process optimization and decreased operational expenses. Healthcare workers apply the technology in patient monitoring systems to obtain real-time data, while minimizing any disturbance to patients. In addition, Zigbee is essential in agricultural applications, since it enables the implementation of smart farming solutions like as soil moisture sensors and automated irrigation systems, which enhance crop output and resource management. The adaptability of this technology is shown in its ability to support a range of applications in smart city projects, such as environmental monitoring, traffic control, and public safety systems. Zigbee is widely preferred for allowing novel wireless solutions in several areas because to its reliability, low power consumption, and scalability

3.3.2. Z-Wave

Z-Wave represents a highly secure wireless communication technology developed specifically for automated home systems and smart home applications. Z-Wave operates in the sub-1 GHz frequency range, providing excellent range and penetration capabilities. This makes it well-suited for bigger residential areas and structures. The mesh networking architecture guarantees dependable communication among devices, even in areas with obstructions or interference. ZWave devices have been designed to operate for long periods on battery power due to to their low consumption of electricity and efficient routing algorithms. This feature significantly contributes to the energy efficiency of smart home systems. Z-Wave devices offer connectivity, providing straightforward integration with an extensive variety of products coming from various manufacturers, boosting a flourishing community of smart home solutions. The technical characteristics of Z-Wave encompass the capability to accommodate a maximum of 232 items on just one network. Additionally, secure communication is guaranteed with the implementation of AES-128 encryption. In addition, Z-Wave’s data transfer rates, which can reach up to 100kbps, allow for fast and efficient operation of smart home appliances. Z-Wave is an effective choice when developing intelligent and resource-efficient home automation systems that enhance accessibility and energy savings for homeowners, due to its reliability, connectivity, and technical knowledge [11].

3.3.3. 6LoWPAN

6LoWPAN, short for IPv6 over Low-Power Wireless Personal Area Networks, is characterized by its capacity to effortlessly include compact, energy-efficient IoT devices into IPv6 networks. 6LoWPAN is a networking technology that enables devices with minimal resources to communicate over the internet by extending IPv6 capabilities. It operates on IEEE 802.15.4 low-power wireless networking. This protocol effectively compresses IPv6 packets, minimizing excess data and preserving energy, which is vital for devices powered by batteries. In addition, 6LoWPAN enables mesh networking, which enables devices to transmit data through nearby nodes, hence improving network dependability and range [12]. 6LoWPAN facilitates the implementation of IoT solutions in several areas such as industrial automation, home automation, entertainment, and smart grid systems by prioritizing power efficiency and enhancing data transfer. The inclusion of IPv6 addressing in its support guarantees the ability to handle larger and expanding IoT deployments, accommodating the increasing quantity of interconnected devices while also ensuring compatibility with future advancements. The technical specifications emphasize that 6LoWPAN is well-suited for constructing resilient and energy-efficient IoT networks that fulfill the requirements of contemporary applications.

3.3.4. Thread

Thread is a fledgling wireless networking protocol specifically developed for home automation devices, with the primary objective of offering a dependable and secure communication option. Thread, backed by major industry players such as Google, Nest, Samsung, and other notable corporations, utilizes the 6LoWPAN protocol to facilitate IPv6 addressing for every device within the network. This guarantees a smooth integration into the wider internet environment, facilitating cloud access and enabling remote monitoring and control. Thread places a high priority on security by using AES encryption, which ensures that data sent between devices and the cloud is protected. Thread, with its strong mesh networking characteristics, can accommodate up to 250 devices in a single local network, guaranteeing scalability for extensive deployments. Thread possesses a distinctive attribute in the form of a networking hub, commonly exemplified by devices such as Nest thermostats, that function as the primary point of communication within the network. These hubs use their own Wi-Fi connection to create an internet gateway for devices that use Thread technology. This allows for smooth connections and improves the overall reliability and performance of the network. Thread is a very promising innovation in home automation technology that provides a strong, secure, and scalable approach for building interconnected smart home environments.

3.3.5. WirelessHART

WirelessHART, developed in 2004, is a wireless communication protocol designed to be compatible with the existing Highway Addressable Remote Transducer (HART) protocol widely used in industrial environments. By providing a seamless transition path for industries seeking to adopt new wireless technologies, WirelessHART allows for the integration of wireless communication into legacy industrial networks without the need for extensive overhauls. This compatibility ensures that companies can upgrade to more advanced, wireless systems while continuing to utilize their existing HART-compatible devices and infrastructure. WirelessHART supports long-range wireless communication, which is crucial for extensive industrial settings where reliable data transmission over large distances is necessary. Its robust design includes features such as self-organizing and selfhealing mesh networks, ensuring high reliability and resilience in harsh industrial conditions. This makes WirelessHART an ideal solution for a variety of applications, including process automation, asset management, and environmental monitoring, where it enhances operational efficiency and reduces the need for costly wiring and maintenance [13].

IV. LONG RANGE WIRELESS COMMUNICATION

Long-range wireless communication enables data transmission over extensive distances, facilitating connectivity in remote and wide-area applications. Some key types of longrange wireless communication technologies include Cellular (4G/5G), LoRaWAN, SigFox, RPMA, and Satellite.

4.1. Cellular

Wide-area wireless connectivity is made possible by cellular technology, the foundation of contemporary mobile communication, which divides geographical areas into smaller areas known as cells, each of which is serviced by a separate antenna or base station. This design enables comprehensive coverage, optimal spectrum utilization, and the capacity to manage a large number of concurrent calls and data sessions. Cellular technology incorporates several multiple access techniques such as FDMA, TDMA, CDMA, and OFDMA to efficiently utilize the available bandwidth and minimize interference. The progression of cellular technology from 1G to 5G has greatly improved the speed at which data is transferred, the capacity of networks, and the delay in transmitting information. 5G, in particular, provides maximum data rates of up to 10 Gbps, extremely low latency, and the ability to handle extensive machine-type communications (mMTC).

The uses of cellular technology are extensive and diverse. In daily life, it facilitates mobile phone conversations, allowing for voice calls, text messaging, and internet connectivity. Cellular networks in business and industry provide dependable and fast connectivity, enabling remote work, teleconferencing, and instantaneous data transmission. The introduction of 5G has broadened its uses, leading to advancements in smart cities, driverless vehicles, and advanced manufacturing by enabling IoT devices and providing ultra-reliable lowlatency communication (URLLC). Cellular technology makes telemedicine, remote patient monitoring, and the transfer of massive medical data files possible in the field of healthcare. Moreover, in the realm of emergency services, it plays a vital role in establishing essential communication channels for first responders and teams responsible for managing disasters. Cellular technology is a fundamental aspect of current communication due to its strong specifications and wide range of applications. It drives progress in different industries and improves daily life.

4.2. LoraWAN

LoRaWAN, also known as Long Range Wide Area Network, is a major advancement in the field of Internet of Things (IoT), providing effective, long-range, and energy-efficient wireless communication capabilities. This protocol functions on unlicensed radio frequency bands, enabling cost-efficient adoption without requiring cellular subscriptions or infrastructure. An outstanding characteristic of this technology is its remarkable coverage, capable of spanning multiple kilometers in urban settings and reaching distances of tens of kilometers in rural regions, surpassing conventional wireless technologies. LoRaWAN is especially appropriate for applications requiring wide-area connection, such as intelligent cities, farm monitoring, and industrial Internet of Things deployments, due to to its enormous coverage. Another important advantage is its low electrical consumption, allowing devices that run on batteries to operate for a long time on just one charge. This makes it particularly suitable for distant and inaccessible areas where regular maintenance is not feasible [14].

LoRaWAN is utilized in several domains such as environmental monitoring, asset tracking, smart metering, and building automation. LoRaWAN technology is used in agriculture to enhance precision farming methods. It enables farmers to remotely monitor soil moisture levels, weather conditions, and crop health. This allows for optimum irrigation schedules and improved agricultural production. LoRaWAN is also used in the logistics industry to track assets and shipments in realtime. This improves visibility in the supply chain and helps to save operational expenses. LoRaWAN enables many different applications in smart cities, including air quality monitoring, street lighting control, garbage management, and parking management. These applications help create more sustainable and efficient urban settings. Furthermore, LoRaWAN is being used more and more in industrial environments for asset management, condition monitoring, and predictive maintenance, all of which help companies run more efficiently and productively [15].

LoRaWAN is growing popularity as an attractive option for organizations seeking to deploy applications for the Internet of Things that require distant communication connection, limited power usage, and efficiency due to its powerful, scalable, and affordable characteristics. The capacity to facilitate effortless communication and exchange of data across extensive distances helps organizations and communities to make decisions based on data, improve operational efficiency, and stimulate innovation in many industries. As IoT network keeps growing, LoRaWAN has the potential to have an essential effect on establishing the future of technologies that are connected and promoting major advancements globally

4.3. SigFox

Sigfox is an innovative technology in the field of Internet of Things, specifically developed to offer extremely narrowband communication with a focus on low energy usage and extensive connectivity. Sigfox operates inside the sub-GHz frequency ranges, specifically 868 MHz in Europe and 915 MHz in the US. It has the ability to cover large distances, with a typical range of up to 50 kilometers in rural regions and 3-10 kilometers in urban contexts. An essential feature of this technology is its remarkably low data rate, usually reaching a maximum of 100 bits per second. This rate is enough for several Internet of Things (IoT) applications that involve sporadic transmission of small data quantities. The emphasis on limited data throughput guarantees that Sigfox devices can function for extended periods on a single battery, making it a perfect option for applications that require longterm deployment and minimal maintenance [16].

The low-power and long-range capabilities of Sigfox make it well-suited for a diverse range of applications in different industries. Sigfox is utilized in smart metering to communicate data from water, gas, and electricity meters to central management systems, facilitating effective resource management and billing. Sigfox enables the surveillance of important assets and equipment across extensive regions in asset tracking. It offers real-time location information, minimizing the chances of loss or theft. Sigfox sensors can be utilized in remote areas for environmental monitoring, enabling the collection of timely data on parameters like temperature, humidity, and air quality. This application is crucial for environmental protection and research purposes. In the field of smart agriculture, Sigfox is employed to oversee soil conditions, livestock movements, and weather patterns, thereby assisting farmers in enhancing their operations and increasing crop harvests. Sigfox is a vital tool for public safety and infrastructure monitoring due to its reliability and vast coverage. It may be utilized to promptly discover and report issues like structural flaws, pipeline leaks, or unlawful entry in real time

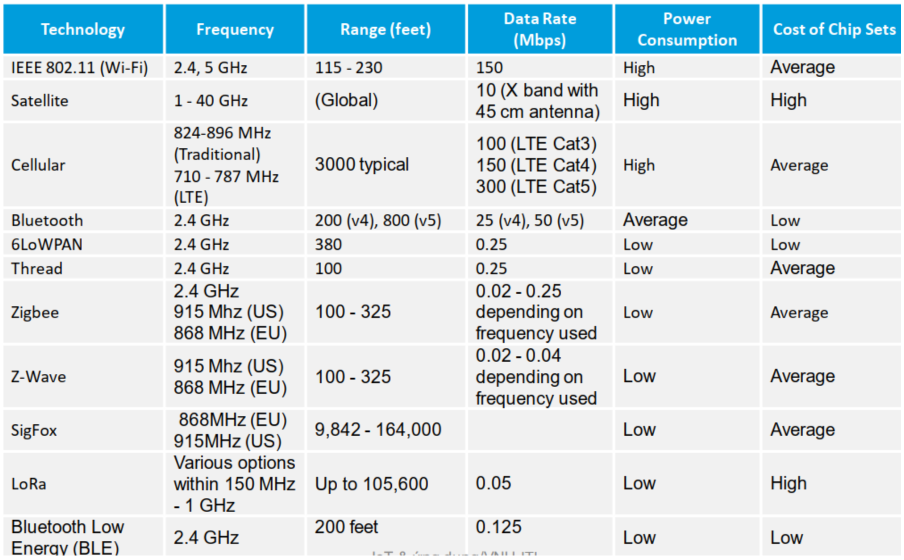
4.4. PRMA

Packet Reservation Multiple Access (PRMA) is a communication protocol designed for efficient data transfer in wireless networks, particularly in mobile and cellular settings. It uses both Time Division Multiple Access (TDMA) and Carrier Sense Multiple Access (CSMA) to allocate time slots for users, enabling contention-based access for initial slot requests and reservation-based access for subsequent data transmissions. This hybrid methodology ensures equitable resource allocation, reducing delays and improving network performance. PRMA's primary specifications include its flexible allotment of time slots, allowing it to adapt to changing traffic conditions, and its ability to facilitate both voice and data transmission. It can manage packets of various sizes and prioritize traffic types, making it adaptable for various service environments. PRMA also has error detection and repair techniques for reliable data transmission in difficult wireless environments. It is particularly suitable for mobile communication systems, cellular networks, wireless local area networks (WLANs), and growing Internet of Things networks. Its ability to efficiently manage high-density traffic in urban environments and highly populated areas enhances network capacity and reliability [17]. Fig. 4 describes a comparison of some wireless communication topologies. We will select the suitable form of wireless communication based on the specific requirements of the application and the users. The prevailing trend in the contemporary world is the adoption of communication standards that facilitate long-distance transmission, require minimal energy, and can be implemented on a wide scale.

V. CONCLUSION

The future of wireless communication in the Internet of Things (IoT) holds great potential for substantial progress and revolutionary effects in multiple industries. Upcoming technologies such as 5G and beyond will offer unparalleled speed, capacity, and dependability, allowing for smoother and more efficient device connectivity. The integration of artificial intelligence (AI) and machine learning (ML) will improve network management and data processing, resulting in more intelligent and agile Internet of Things (IoT) ecosystems. Advancements in low-power wide-area networks (LPWAN) will expand the coverage of IoT devices, especially in distant and rural regions, promoting increased inclusiveness. The importance of security will continue to grow, as improved encryption and blockchain technologies are used to guarantee the privacy and reliability of IoT communications. In addition, using edge computing will decrease latency and bandwidth usage by analyzing data in proximity to its origin, hence enhancing performance. These advancements will not only transform sectors like healthcare, agriculture, and smart cities but also create opportunities for new uses and services, leading to the emergence of a highly interconnected global society.Within the IoT network, numerous wireless technologies exist, each possessing distinct requirements and advantages. Nevertheless, determining the absolute perfection of either option is a challenging task. Hence, the crucial inquiry that must be addressed is ”which technology is most suitable for my specific application.” This paper examines and contrasts the prevalent communication protocols in the Internet of Things from a particular perspective. Various criteria are employed to compare communication protocols. The requirements encompassed in this context are network, topology, power, range, cryptography, spreading, modulation type, coexistence with mechanism, and power consumption.

Figure4. Comparision among wireless communication topologies



Technology	Frequency	Range (feet)	Data Rate (Mbps)	Power Consumption	Cost of Chip Sets
IEEE 802.11 (Wi-Fi)	2.4, 5 GHz	115 - 230	150	High	Average
Satellite	1 - 40 GHz	(Global)	10 (X band with 45 cm antenna)	High	High
Cellular	824-896 MHz (Traditional) 710 - 787 MHz (LTE)	3000 typical	100 (LTE Cat3) 150 (LTE Cat4) 300 (LTE Cat5)	High	Average
Bluetooth	2.4 GHz	200 (v4), 800 (v5)	25 (v4), 50 (v5)	Average	Low
6LoWPAN	2.4 GHz	380	0.25	Low	Low
Thread	2.4 GHz	100	0.25	Low	Average
Zigbee	2.4 GHz 915 Mhz (US) 868 MHz (EU)	100 - 325	0.02 - 0.25 depending on frequency used	Low	Average
Z-Wave	915 Mhz (US) 868 MHz (EU)	100 - 325	0.02 - 0.04 depending on frequency used	Low	Average
SigFox	868MHz (EU) 915MHz (US)	9,842 - 164,000		Low	Average
LoRa	Various options within 150 MHz - 1 GHz	Up to 105,600	0.05	Low	High
Bluetooth Low Energy (BLE)	2.4 GHz	200 feet	0.125	Low	Low

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