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OVERVIEW OF WIRELESS TECHNOLOGIES IN WIRELESS PERSONAL AREA NETWORKS FOR IoT INTEGRATION IN SMART CITIES

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Abstract

The main goals of the development of smart cities are to improve the quality of life of citizens, to improve energy efficiency and to reduce the emission of greenhouse gases. The use of modern technologies, such as wireless networks and Internet-based applications, has made smart cities a reality. The development of wireless communication technologies enabled the application of the Internet of Things (IoT) concept. IoT technology is key for development of smart cities because it has made it possible to connect all devices and city infrastructure via the Internet. The goal of the research was to review wireless technologies in Wireless Personal Area Networks (WPANs) for IoT applications. The characteristics of Bluetooth, ZigBee and Z-Wave technologies, their application in the IoT concept, advantages and disadvantages are analyzed. The aim of the research was to compare these three technologies in terms of speed, coverage, energy efficiency, accessibility, cost and network capacity.

Keywords: *Bluetooth, ZigBee, Z-Wave, WPAN, Internet of Things (IoT)*

INTRODUCTION

In recent decades, cities have been facing numerous problems such as pollution, difficult access to infrastructure, traffic jams, poor mobility, endangered safety and health of residents. It is known that today over 55% of the world's population lives in urban areas [1], and that by 2050 that percentage will increase to over 70% [1, 2]. Numerous scientists and researchers

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have been working intensively for years on the development of technologies that will change the way cities function.

Smart cities can be viewed as ecosystems of smart solutions in which actors and stakeholders dedicated to sustainable development are gathered and in which new technologies are used to achieve sustainability goals (economic, social and environmental aspects of development) [1]. Smart cities imply the concept of a city that is completely connected and equipped with technology with the aim of improving the lives of residents.

According to research, the implementation of the smart city concept can annually reduce the emission of harmful gases with the greenhouse effect by 10-15%, as well as the amount of solid waste per person by 10-130 kg [1]. Also, it is possible to achieve a lower crime rate of up to 40%, to increase support for sick people by 8-15%, to save 25-80 liters of water per person in one day and to achieve 20-35% faster times emergency response [2]. In order to achieve these results, it is necessary to have three levels of smart technologies that build on the existing technical and social infrastructure. The first level is a network of connected devices and sensors. The second level is represented by smart applications and data analysis that are used to transform raw data into notifications, alerts, conclusions and specific actions. The third level implies the widely accepted use of applications in cities, the business sector and among citizens, with efficient data management, which results in a quality decision-making process and changes in behavior patterns [1]. The latest IoT Analytics report shows that the number of global IoT connections grew by 18% in 2022 to 14.3 billion active IoT endpoints [3]. Research indicates that there will be at least 88 smart cities by 2025, because those cities already have urban development plans made until 2025 [2].

The key technology for the development of smart cities is the Internet of Things, which has made it possible to connect all devices and city infrastructure via the Internet. The IoT concept implies the communication of all devices that can be connected to the network, which function based on the data they receive from each other, using built-in sensors, processors and communication hardware. The application of IoT enables the monitoring and management of resources such as energy, water, traffic and waste in real time. In this way, efficient use of resources is enabled.

The paper analyzed wireless communication technologies eseential for development of wireless personal networks in smart buildings. A comparative review of three technologies was performed: Bluetooth, ZigBee and Z-Wave. Their characteristics, application, advantages and disadvantages are analyzed. A comparison of these three technologies was made regarding speed, coverage, energy efficiency, accessibility, cost and network capacity.

THE IMPORTANCE OF WIRELESS COMMUNICATION TECHNOLOGIES IN THE DEVELOPMENT OF THE IoT CONCEPT

The development of smart cities sets very specific requirements for wireless communication technologies in terms of connection stability, data transfer speed, effective use of the frequency spectrum, low consumption, etc. Wireless technologies make it possible to connect a large number of different IoT devices to the Internet without the need for physical cables.

IoT implies the use of sensors and the application of wireless communication technologies in all types of physical objects. IoT, among others, includes: traffic congestion sensors, water level monitoring, parking space applications, waste management sensors, fire detection sensors, energy monitoring, surveillance cameras, lighting control, etc.

Some of the basic roles of wireless communication technologies in the IoT system are:

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- Device connectivity – Wireless technologies allow various IoT devices to connect to the Internet. This way, the exchange of data between devices is enabled, as well as the exchange between devices and central systems for data processing and analysis.
- Mobility – Wireless technologies enable IoT devices to be mobile and communicate across locations.
- Low power consumption – Some of the wireless technologies, such as ZigBee and LoRaWAN, are optimized for low power consumption. This feature makes them suitable for IoT devices that run on battery power or in applications where battery life is extremely important.
- Scalability - The application of wireless technologies allows for easy addition of new devices to the IoT network without the need for physical modifications to the infrastructure. This way, the rapid growth and scalability of the IoT system is enabled.
- Flexibility - The application of wireless technologies does not require the installation of cable infrastructure, which allows for great flexibility in the implementation of IoT systems. This facilitates the implementation of IoT solutions in various environments, including urban and rural infrastructure.
- Interoperability – The integration of different wireless technologies enables interoperability between different devices in an IoT system. This is of great importance for the implementation of solutions that use a combination of different sensors, devices and platforms.

INTEGRATION OF WIRELESS NETWORKS WITH IoT DEVICES

In accordance with the division of smart city networks, which are divided into: WPAN - Wireless Personal Area Network, WLAN - Wireless Local Area Network and WMAN - Wireless Metropolitan Area Network, wireless communication technologies can be classified. In order for IoT devices to function optimally, it is necessary to apply appropriate communication technologies.

WMAN technologies are based on IEEE 802.16 standards. Technologies that are most in use are WiMax, LTE, LTE-A, LoRaWAN. In smart cities, they are applied for wireless Internet access in wider areas, for connecting remote sensors and devices, smart water supply management, connecting mobile vehicles and devices, monitoring energy consumption, etc.

WLAN technologies are based on IEEE 802.11 standards. In smart cities, they are used to monitor public spaces, monitor public transport, smart lighting, manage energy consumption, etc.

WPAN is based on the IEEE 802.15 standard. WPAN networks play a significant role in the management of various IoT devices, their control and automatic connection. They are used in smart homes to control lighting, heating, air conditioning and security systems. It can also be used in industry to monitor production processes, monitor inventory and manage logistics, etc. Typical examples of WPAN technologies are Bluetooth, ZigBee, Z-Wave, which differ the most in terms of complexity and degree of security. Some other WPAN technologies are: WirelessHart, ISA100.11a, 6LoWPAN, Wibree, Insteon, Wavenis, ANT+, Enocean and CSRMesh [4].

Figure 1 shows a graphic representation of the range of networks in smart cities with associated technologies.

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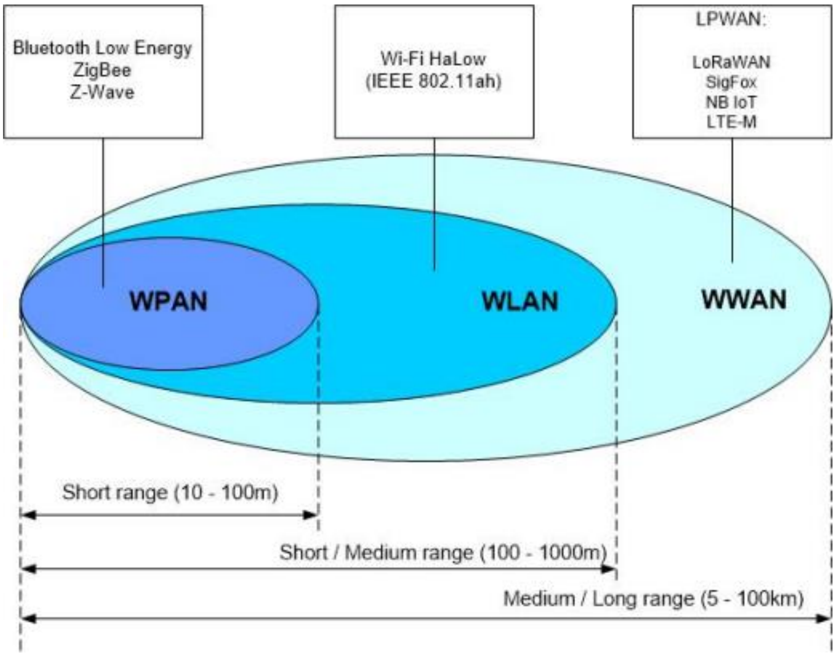

Figure 1: Wireless access geographic coverage

Wireless technologies in WPAN networks support point-to-point, star, and mesh topologies. The simplest form of wireless network topology is a point-to-point network in which nodes communicate directly with a central node. In the star topology, which is shown in Figure 2a, there is one gateway node to which all other nodes are connected. Nodes can only communicate with each other via the gateway. Node messages are relayed to a central server via gateways. Each end node transmits the messages to one or multiple gateways. The gateway forwards the messages to the network server, where redundancy, errors, and security checks are performed [4]. The network implemented in this way is fast and reliable. Faulty nodes in the network can be easily identified and replaced. However, in the event of a gateway failure, all nodes connected to it are unavailable. The elements of the mesh topology, which is shown in Figure 2b, are sensor nodes, gateway nodes and sensor-cum-routing nodes [4]. A gateway is a complex device that is the root of the network tree and enables connection to other networks. In every network there is one gateway that stores network information. A sensor-sum-routing node is an optional element that routes traffic in the network. It has routing tables and assigns addresses to end devices. When it successfully delivers a message to an end device, it updates its best-path records to help route requests in the future. A sensor node communicates with a parent node, routing node or gateway, but cannot communicate with other devices. This type of device consumes less energy than the previous two types.

The advantages of this topology are availability of multiple routes for reachability, simultaneous up/downstream transmissions, easy scalability of the network, and capability of self-healing [4]. The disadvantages of this topology are an increase in the complexity of the network, an additional latency due to the increased number of hops in the network, and an increase in the cost of implementing this topology.

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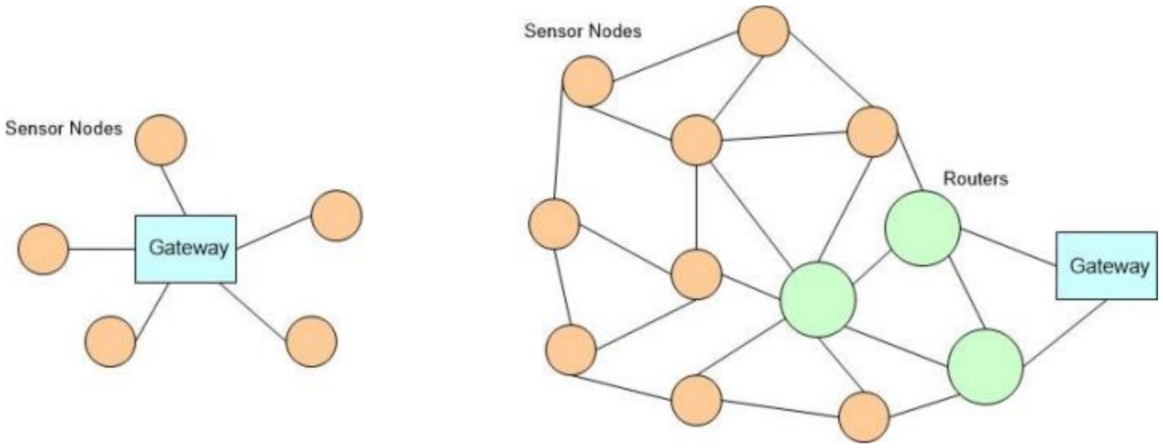

Figure 2: (a) Star topology, (b) Mesh network topology

OVERWIEV OF WIRELESS TECHNOLOGIES IN WPAN

Basic Features Of Bluetooth

The most common standard in WPAN network is IEEE 802.15.1 with the commercial name Bluetooth. Bluetooth is a technology used for short-range wireless communication. Bluetooth devices are low-power transceivers that operate in the ISM (Industrial, Scientific and Medical) frequency range of 2.4GHz.

Given the nature of radio waves and the FHSS (Frequency Hopping Spread Spectrum) transmission technique, these devices do not need to be in line of sight to communicate. The available frequency range of 83.5 MHz is divided into 79 channels of 1 MHz width. Each transmission lasts 625 µs, that is, channel change occurs 1600 times per second [5]. A classic Bluetooth network consists of one master device and a maximum of seven slave devices. The master device determines the frequency hopping scheme, while the other members of the pico network use the same arrangement. Due to this feature, it is possible to have multiple piconets at a small distance from each other because each uses a different form of frequency hopping.

The transmission speed achieved by Bluetooth devices is sufficient for real-time voice and data transmission. Due to their small dimensions, great functionality and flexibility, as well as low prices, Bluetooth devices are used in many modern telecommunications systems, allowing users to exchange data in a simple way.

BR/EDR (Basic Rate/Enhanced Data Rate) Bluetooth provides a constant wireless connection and uses a point-to-point topology to establish a connection between two devices. BR/EDR technology supports data transfer rates from 0.7 to 2.1Mbps and a range of up to 100m. Therefore, it is applied where there is a need for faster data transfer.

Bluetooth LE (Low Energy) is a very low consumption technology, it has twice the range and data transfer speeds of up to 2Mb/s. In BLE mode, the available frequency range is divided into 40 channels with a width of 2 MHz, thus achieving a higher transmission speed. The main drawback of BR/EDR technology was the inability to use it in applications that require wide coverage and the limitation of 8 devices in a pico network. These problems were overcomed within BLE with the introduction of mesh topology. Compared to the star topology, mesh topology can suffer less damage when its nodes fail, increasing the reliability of networks [6]. By introducing new functionalities, BLE technology is starting to be used more in the IoT concept where energy conservation is the primary task. Also, BLE

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technology is very cheap to implement, which is of great importance when choosing the technology to be implemented in smart cities.

The Bluetooth Special Interest Group (SIG) is responsible for creating the Bluetooth standard. Until the development of Bluetooth version 4.1, the primary goal was to connect devices with a low-power radio signal, such as connecting a smartphone and headphones or a television and a remote control [5]. The new features introduced in version 4.2 enabled Bluetooth LE to become a promising technology that contributes to the development of IoT [5].

A significant advance in the development of this technology was achieved with version 5.0, which achieved two times the transmission speed, four times the transmission range, and eight times the broadcasting capacity of Bluetooth 4.2 [6]. The latest version of the Bluetooth standard is V5.4. Compared to previous versions, this version introduces improvements in terms of lower power consumption, increased data transfer speed, improved privacy and increased range [7, 8]. Bluetooth 5.4 adopts more efficient low power technology and thus enables devices to save energy without any loss in performance. The maximum data transfer speed is 2Mbps. Bluetooth 5.4 supports encryption algorithms where key size control is enabled. This means that it is now possible to choose whether the device uses longer keys or faster encryption algorithms depending on the user's needs (speed vs. security). Bluetooth devices encrypt data to protect it, and the security of this encryption depends in part on the length of the key. The ability of the host to specify a minimum key size reduces the amount of communication between transmitter and receiver.

In addition to numerous advantages such as low consumption, ease of use and wide application, Bluetooth technology also has certain disadvantages. Due to the limited bandwidth and maximum data transfer rate of 2Mbps, this technology is not suitable for high speed data transfer [9].

Basic Features Of ZigBee

ZigBee is a wireless technology designed for remote control and sensor devices based on the IEEE 802.15.4 standard. The standard was established under the auspices of the ZigBee Alliance and introduced the new concept of LR (Low Rate) personal wireless networks. This technology is used in IoT applications that require wireless transmission of small amounts of data over shorter distances. The communication distance is 10 to 20 meters with the possibility of covering longer distances through mesh topology. ZigBee enables simple, cheap and efficient connection of devices in Wireless Sensor Networks (WSN). It operates in one of three ISM bands: 868 MHz in Europe, 915 MHz in the USA and 2.4 GHz in the rest of the world [10, 11]. In this way, the standard is available to the whole world. ZigBee has three types of different devices which are: the coordinator, the router and end device [12]. Zigbee supports star, tree and cluster mesh topology [11, 12]. Mesh topology is the most flexible topology of the three. Flexibility is present because a message can take multiple paths from source to destination. If a particular router fails, then ZigBee's self-healing mechanism will allow the network to search for an alternate path for the message to be passed [13].

Operation in the range 868-868.6 MHZ implies the use of one channel, in which BPSK modulation is applied, and the maximum speed that can be achieved is 20kbps [10]. Higher transmission rates (up to 250kbps) can be achieved in the 2.4GHz band, where 16 channels and 16QPSK modulation are used [11]. The low data transfer rate satisfies dedicated

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applications within intelligent apartments, offices, infrastructure, etc. ZigBee networks can contain up to 653356 devices, and these devices can be separated by 50m [12].
The standard supports 64-bit IEEE addresses as well as short 16-bit addresses. 64 bit addresses uniquely identify each device with each device's unique IP address in the same way that devices have a unique IP address. Once a network is established, 16-bit addresses can be used. It allows support an extremely large number of devices, as opposed to the 7 supported by, for example, BLE 4.2.
ZigBee systems can work in environments where the degree of interference with other devices is extremely high. This technology implies low-power devices, which allows battery life to be measured in years [10].

Basic Features Of Z-Wave

Z-Wave is a wireless technology developed by the Zensys community primarily intended for the automation and monitoring of IoT devices within the household. This technology has low energy consumption and low data rate [14]. It achieves this by means of two types of signal modulation, PSK at speeds of 9.6 and 40Kbps and GFSK modulation for speeds up to 100Kbps. Also, ZigBee uses CSMA/CA technology to solve the problem of interference with other devices, but it supports significantly fewer devices in the network, more precisely 232 [15]. It uses a frequency range of 900MHZ (USA), and in Europe 868.4MHz, which allows a range of up to 30m indoors and 100m in an open space.
Z-Wave supports mesh topology. The network consists of one primary and one or more secondary controllers that control other devices (slave devices). Control devices in the network are nodes that initiate control commands and send them to other nodes. Slave devices are nodes that execute or respond to received commands, but are also able to forward commands to other nodes in the network. In this way, the main controller is enabled to establish communication with nodes that are not in its signal range.
It is necessary to define two more terms for the Z-wave network, namely the Home ID and the Node ID. The Home ID is a 32-bit identifier that is pre-programmed into all home controllers, and is required by a node if it wants to join the network. Slave nodes are not connected to the network and their HOME ID value is zero. If the slave node accepts the Home ID of the master controller, it becomes part of the network. Master controllers can exchange their Home ID with other controllers and thus connect them to the network and enable them to manage the existing slave nodes in the network. Slave nodes have their own 8-bit identifier assigned to them by the master controller to identify each node [15].
The advantage of using Z-Wave technology in a WPAN network is its reliability, low energy consumption, and the ability to support a large number of devices in the same network. Also, Z-Wave is designed to operate in a frequency range that is less susceptible to interference which further improves its reliability in a smart home environment.
The vulnerability of the Z-wave network is that the master controller must be constantly connected to the Internet. A problem arises due to the possibility of a foreign controller intruding into the network, which remains invisible to the rest of the network after the intrusion, and thus has the ability to manage nodes [16].

COMPARISON OF WPAN WIRELESS TECHNOLOGIES

ZigBee and Z-Wave technologies were primarily used for building and home automation before the development of Bluetooth 5.0. Before Bluetooth technology replaces these two

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technologies in certain applications, it is necessary to examine the justification of this replacement. Table 1 shows a comparison of BLE 4.2, BLE 5.0, ZigBee and Z-Wave technologies [6]. The technologies were compared in terms of speed, coverage, energy efficiency, accessibility, cost and network capacity.

Table 1: Comparison of WPAN wireless technologies

Technology		Bluetooth		ZigBee	Z-Wave
		BLE 4.2	BLE 5.0		
Speed	Maximum Data Rate	1Mbps	2Mbps	250kbps	40kbps
Coverage	Transmission Range (indoor)	10-20m	40m	10m	30m
	Mesh Support	No	Yes	Yes	Yes
Energy Efficiency	Battery Life	High	High	High	High
Accessibility	Existence in Cell Phone	Yes	Yes	No	No
Cost	Module Price	1-5	5-10	1-5	1-5
	Additional Router	No	No	Yes	Yes
Network Capacity	Maximum Number of Nodes	8	32 767	>65 000	232

Data transfer rate is a very important parameter when choosing communication technologies because different transfer rates correspond to different levels of messages. For example, Z-Wave technology, which can achieve a maximum transmission speed of 40kbps, can only be used for the transmission of small data packets. In this comparison of technologies, it is necessary to take into account that high transmission speed is not necessary for the automation of buildings and houses. Also, a higher data rate transmission requires a higher bandwidth and a more complex modulation scheme, which leads to higher power consumption and more expensive hardware.

The transmission speed of Bluetooth technology enables several times higher transmission speeds compared to ZigBee and Z-Wave technologies. The transmission speed for BLE 5.0 is doubled compared to BLE 4.2 [17, 18] and amounts to a theoretical 2Mbps.

When choosing the technology to be used in the IoT concept, it is necessary to pay attention to the maximum range that can be achieved. This is especially important with technologies that have a star topology. With technologies that support mesh topology, greater coverage can be achieved, but with an increase in signal transmission delay.

Compared to Bluetooth technology, ZigBee and Z-Wave have a shorter signal range. However, these two technologies achieve greater coverage by using a mesh topology. For home automation, the application of Bluetooth technology before version 5.0 was not appropriate because not only it could only transmit at a short range but also lacked mesh functionality [6]. For the application of wireless technologies in WPAN, the support for the network topology is extremely important in order to be able to open the coverage of large areas. With the development of Bluetooth 5.0, this technology becomes competitive with ZigBee and Z-Wave technologies.With Bluetooth 5.0, the range has been increased four times. In fact, in the worst case, this range should be 200 meters outdoors and about 40 meters indoors [19].

Energy efficiency has a big impact on the user experience when using IoT devices. It is extremely important for devices that exclusively use battery power. With the development of BLE and Bluetooth technology, it has become competitive with ZigBee and Z-Wave in terms

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of energy efficiency. BLE, ZigBee and Z-Wave are technologies with extremely low power consumption and allow a battery life of one month to one year [17].

Today's mobile devices have a built-in Bluetooth module, so there is no need to purchase an additional controller for users of IoT systems that use Bluetooth for control and communication. The existence of Bluetooth modules in mobile phones gives this technology an advantage over ZigBee and Z-Wave because the application of Bluetooth technology represents a better choice in serving datadriven applications and applications requiring massive deployment [6].

In IoT applications where there is an extremely large number of devices, it is necessary to take into account the costs incurred during the implementation of a certain technical solution. The total costs are affected by the price of the individual IoT device, such as whether an additional router is necessary for implementation. As shown in Table 1, Bluetooth 5.0 modules are slightly more expensive than other modules, but do not require the use of an additional router [6].

Network capacity refers to the maximum number of devices that can work in the network. With the development of BLE 5.0, the capacity of the network has been significantly increased and tens of thousands of devices can be connected [20]. Z-Wave technology has the smallest network capacity, with slightly more than 200 devices, but this capacity is also satisfactory for many applications at the house/building level.

Based on the previous comparisons, it can be concluded that the competing technologies in WPAN networks are Bluetooth and ZigBee. Both technologies are low power, low cost and support network topology. With the development of Bluetooth 5.0 technology, the shortcomings in terms of coverage and network capacity were compensated [20]. In relation to data transfer rates, single-link connection and availability, Bluetooth technology has an advantage over ZigBee, while these technologies are similar in terms of energy efficiency and price.

Future research on Bluetooth technology is focused on integration with artificial intelligence. The combination of these technologies can have significant application in the advancement of smart homes where it can improve the control of intelligent home devices. The integration of Bluetooth technology and Blockchain technology could potentially improve data security and privacy. Some of the other challenges in the advancement of Bluetooth technology are related to improving data security, solving compatibility issues between multiple existing versions of Bluetooth technology, as well as controlling energy consumption in cases where Bluetooth technology is used in long-running devices (such as smart homes) [8]. A more significant application of the technologies defined in the latest versions of the Bluetooth standard is expected. For example, angle positioning technology based on Bluetooth 5.1 can bring more accurate and efficient location services to smart cities and smart homes [8]. Also, Bluetooth LE audio technology based on Bluetooth 5.2 can support higher quality and lower power audio transmission [8].

CONCLUSION

As the evolution of the network continues, smart cities must keep up with the changes and be ready to increase network capacity to accommodate the expected exponential growth in data traffic. WPAN networks play a key role in the development of the IoT concept because they enable the connection of a large number of devices. With the development of artificial

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intelligence, machine learning, data analysis and Blockchain technologies, there is a huge potential for the development of WPAN applications in all sectors of society.
The existence of several wireless technologies with different characteristics enables the selection of the optimal technology depending on the specific requirements of the application. Further development of wireless technologies in WPAN networks will contribute to expanding the possibilities of application in various IoT scenarios and increasing the number of IoT devices. Therefore, it is necessary to pay special attention and find adequate solutions to the potential congestion of the frequency spectrum and increased interference between devices.

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