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Key Technologies, Applications and Trends of Internet of Things for Energy-Efficient 6G Wireless Communication in Smart Cities

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Abstract: Smart cities can be made into super-smart cities through IoT devices' implication of energy-efficient 6G. IoT devices are expected to reach fifty billion, but limited information is available regarding the energy-efficient 6G wireless communication standard. This article highlights the key technologies, applications, and trends in the Internet of Things (IoT) for energy-efficient 6G wireless communication in smart cities. The systematic review helped to achieve the aim of the study by considering the 20 articles extracted from databases and Google that fell between 2015 and 2021 and are written in English. The findings identified that quantum communication, blockchain, visible light communication (VLC), 6G brain–computer interface (BCI), symbiotic radio, and others are the key technologies. The applications of IoT technologies and energy-efficient 6G are found in 15 Minute City, Industrial Town, Intelligent Transport systems and others. Furthermore, the trend of using 6G through IoT devices in smart cities is promising.

Keywords: 6G; energy-efficient; Internet of Things (IoT); key technologies; smart cities

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1. Introduction

6G wireless communication is a successor of 5G communication. As per Akhtar et al. [1], it uses a higher frequency than any of its predecessors and provides a higher capacity and lower latency. This helps the technology to integrate communication over land, water, and air into one network with higher speed and reliability. This is a very important prerequisite for the large-scale adoption of the IoT. As stated by Ranger [2], the devices connected to IoT infrastructure are expected to reach billions, and this connection will ultimately depend on the speed of connectivity. It should also be noted that, at present, very little information is available on the standard of 6G wireless communication. However, given the rapid scale of the progression of communication from 2G to 5G in the space of a few years, the arrival of 6G communication is inevitable. This will eventually be a potential game-changer, as this technology would disrupt the current state of technology and intelligence. This is discussed by Zhao et al. [3], who point to the revolutionary nature of 6G communication, as it can have a wider frequency with greater communication transmission. Given the increasing role of artificial intelligence (AI), it is doubtless that 6G wireless communication will have a very important role to play in the future. This is because, unlike 5G, 6G does not require high power consumption and can be considered highly secure. Security is among the key issues that confront communication and IoT. This is because the current web is built on technology created over 50 years ago. Since then, there has been no major improvement in the web. However, as more devices are connected to the internet, a new challenge has been posed, as academicians and practitioners need to adapt to the changing role of technology. Furthermore, the main limitation of 5G and other previous networks is that they are insufficient to fulfill the connectivity requirements of 2030 and above. For example, 5G is limited to typical scenarios; therefore, villages and motorways are not well-covered, and a transition from classical technologies to 6G is required. Therefore, the main limitations of the previous networks are the security, coverage, and other concerns, which urge the need for 6G communication, especially in smart cities.

In addition, as the research and markets show [4], there is a need for a critical re-assessment of smart cities in the realm of energy-efficient 6G communication. This should consider IoT infrastructure, market factors that could lead to a faster adoption rate, and strategies that enable the operations of smart cities. Smart cities are built on the principle of increased connectivity; thus, the existing communication infrastructure cannot enable the growth and operation of smart cities. This is one of the core reasons that the world should move towards the faster communication rate provided by energy-efficient 6G communication channels. Hence, it can be concluded that the development of smart cities occurs in tandem with the development of energy-efficient 6G communication. It is also acknowledged in the research and markets [4] that global investment in the infrastructure development of smart cities will exceed USD 3.6B, making it one of the next big things. Under this backdrop, it is important to carve out the technologies, trends, and applications of 6G wireless communication, which will remain the objective of this study.

1.1. Research Aim and Objectives

This research paper aims to highlight the key technologies, applications, and trends in IoT for energy-efficient 6G wireless communication in smart cities. Three objectives have been developed to accomplish this research aim for 6G wireless communication in smart cities.

RO1—Craving out the key technologies of the IoT for 6G wireless communication in smart cities.

RO2—Identifying the popular key technology applications for 6G wireless communication in smart cities.

RO3—Highlighting the trends in IoT technologies.

1.2. Research Significance

The increased realm of 6G key technologies leads to faster adoption strategies that enable the operation of smart cities. Therefore, it is very important to highlight the key technologies, applications, and trends in the IoT for 6G in smart cities. Based on the research aim, the study results are highly significant for technology companies, government officials, scholars, and smart city management. The report results provide a holistic view of popular IoT 6G wireless communication technologies, which could enable smart cities to perform operations with high-speed connections. This allows technology companies to predict future trends and manufacture communication devices for smart cities accordingly. In addition, it helps government officials and smart city management to maintain the essence of building smart cities by adopting technologies that are relevant to 6G fastest wireless communication. Moreover, the result fills the gap in the literature, where limited information is available related to 6G wireless communication technologies, applications and trends. This shows the significance of our study.

1.3. IoT for 6G in Smart Cities

A range of technologies that need to be described for the full-scale development of the 6G communication network. The study of Liu et al. [5] highlighted different technologies that can be useful in 6G wireless communication. These technologies include the Internet of Things (IoT), virtual reality (VR), Terahertz (THz) communication, visible light communication, etc. IoT is also discussed by Liu et al. [5], who states that the current state of communication networks, i.e., 5G, is relatively slow at keeping the billions of devices connected to IoT systems, as they require massive data processing and communication in real-time. As a result, scientists are already looking forward to a faster form of communication that can open up a new era in terms of connectivity.

1.4. Trends

Regarding the recent trends in 6G communication, the study of Sher et al. [6] has provided significant insights. Intelligent connectivity is the leading trend in 6G communication. This is because the earlier systems of communication, such as 4G or 5G, do not possess the technical sophistication needed for the rapid development of intelligent connectivity. It has been a challenge for 5G networks to provide a single network platform that can enable enhanced connectivity. This is clearly unsupported by the current state of communication networks and requires high-speed networks such as 6G that rely on artificial intelligence for network services and edge computing. Another emerging trend discussed in the realm of 6G is the use of IoT systems. Wang et al. [7] stated that the major motivation behind the use of 6G in IoT systems is to effectively connect each and every device to the network. Based on the network speed of 6G connectivity, technologies based on IoT can enable the integration of many technologies and communication between devices that could not previously have been connected. It can also provide real-time data processing and communication and provide users with an excellent user experience in different IoT applications, such as smart homes and smart cities. However, this trend is largely undeveloped due to the limited research that has been conducted and high cost of implementation [8]. In future, given the rate of technological advances and the current interest shown by countries such as China and the US in the development of 6G, it is only a matter of time before 6G is widely applicable in IoT systems in smart cities. The aspect of security in the development of 6G communication also needs to be highlighted. As per Wang et al. [7], security is one of the key features leading to the advancement of a new communication paradigm, also known as 6G communication. In addition to the major aspects of the 6G network, such as real-time intelligent edge computing, distributed artificial intelligence, intelligent radio, and 3D intercoms, the issues of security and privacy must also be brought into the limelight. Through the advanced security system that is possible in 6G, the smart cities' IoT-based systems will be more secure, to keep up with the expectations of privacy and confidentiality. The study has illustrated the evolution of security under different networks; see Figure 1.

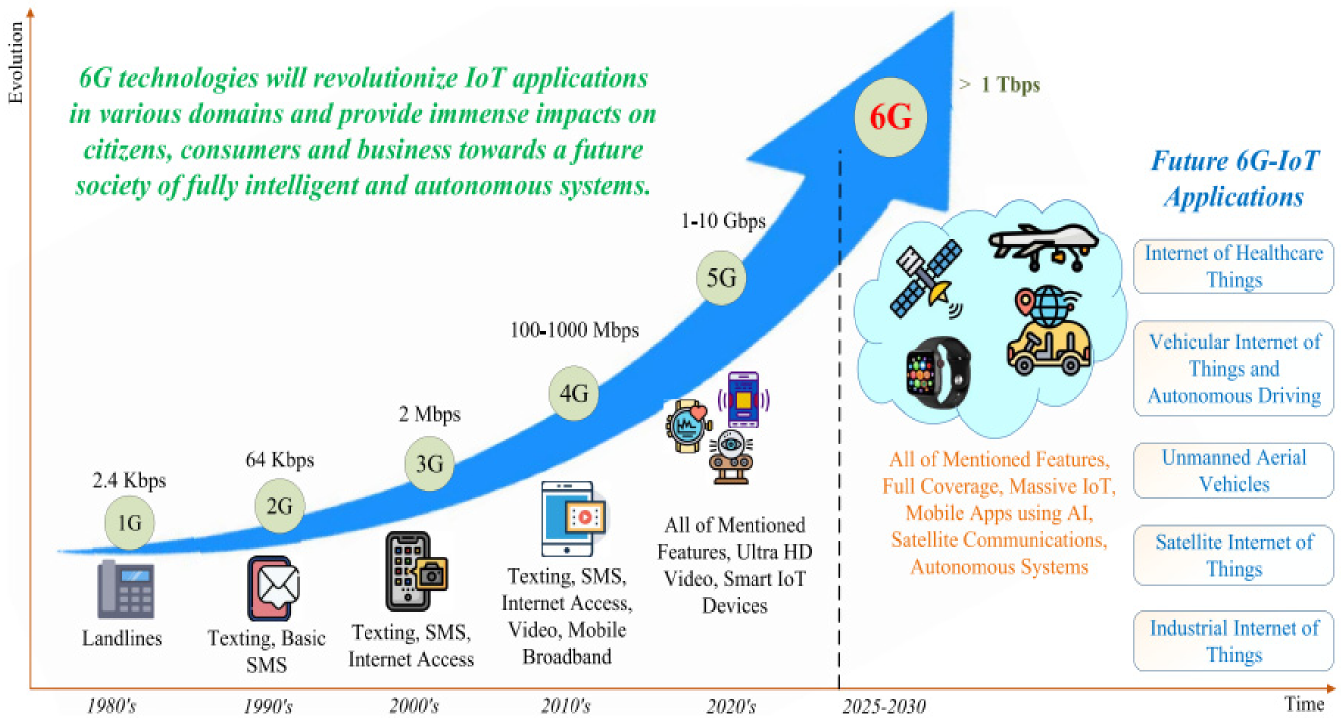

Figure 1. Phases in the development of networking technology source [9].

2. Methods and Materials

The main methodology used in our study is a systematic review. As discussed by Aromataris and Pearson [10], a systematic review is achieved through a critical assessment of different academic papers. This is essentially a review of the evidence and proven concepts regarding the formulated research objectives. In such a study, it is left to the researcher to select, screen, and critically analyze different studies. The study is dictated with the purpose of stating the summary and findings of the primary or secondary research conducted on the chosen topic. In this manner, a systematic review can also be referred to as secondary research, since it is based on a meticulous review of academic papers. The papers selected for this study are highly technical. They were obtained through searching for keywords such as "6G Network," "6G Network Applications," "Technologies," "Trends," and "Internet of Things (IoT)". The minimum number of papers that was reviewed in this study is 20. This was to make the study comprehensive and inclusive. However, it must also be noted that this study is not limited to summarizing different academic papers; the author's own discussion and analysis are also a key aspect of this study. The inclusion criteria were that the study only considers articles published from 2015 to 2022. The study excludes blogs and news to ensure the quality of content. The bias in the extraction of studies, selected using Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA), is shown in Figure 2. The AMSTAR results for this study are presented in Table 1. In Appendix A, Table A1, shows the results of the systematic literature review conducted in the study.

Table 1. AMSTAR results.

	Study Type ($n = 60$)	
	Number	**Percentage**
Overview	39	65%
Methodological	21	35%
	Study designs ($n = 60$)	
Descriptive	27	45%
Experimental	33	55%
	AMSTAR assessment ($n = 60$)	
Yes	19	32%
No	41	68%
	Number of reviewers in total ($n = 60$)	
2	11	18%
>2	49	82%
	IRR reported ($n = 60$)	
Yes	42	70%
No	18	30%
	Publication Year > 2015 ($n = 60$)	
Yes	58	23%
No	2	77%

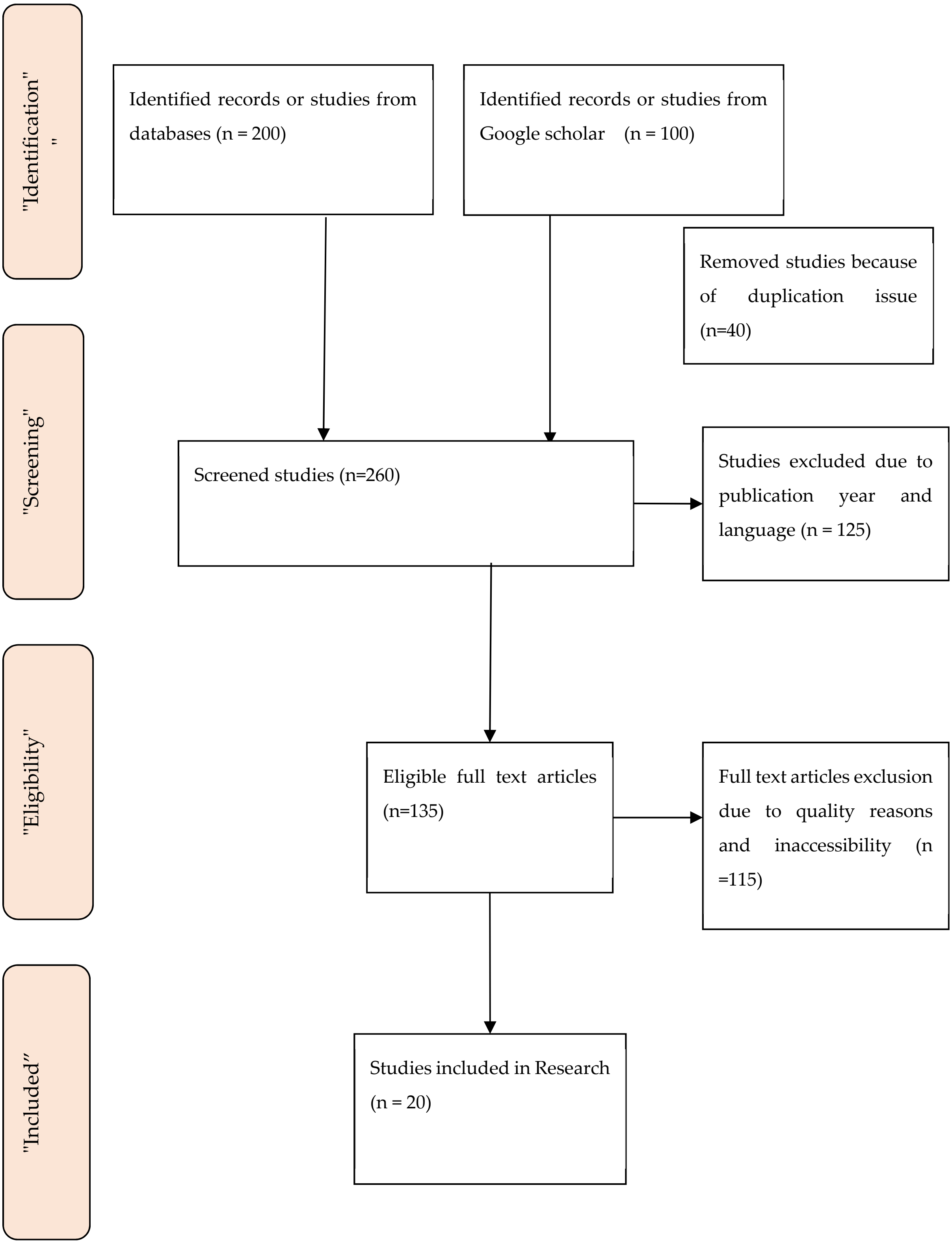

Figure 2. *Cont.*

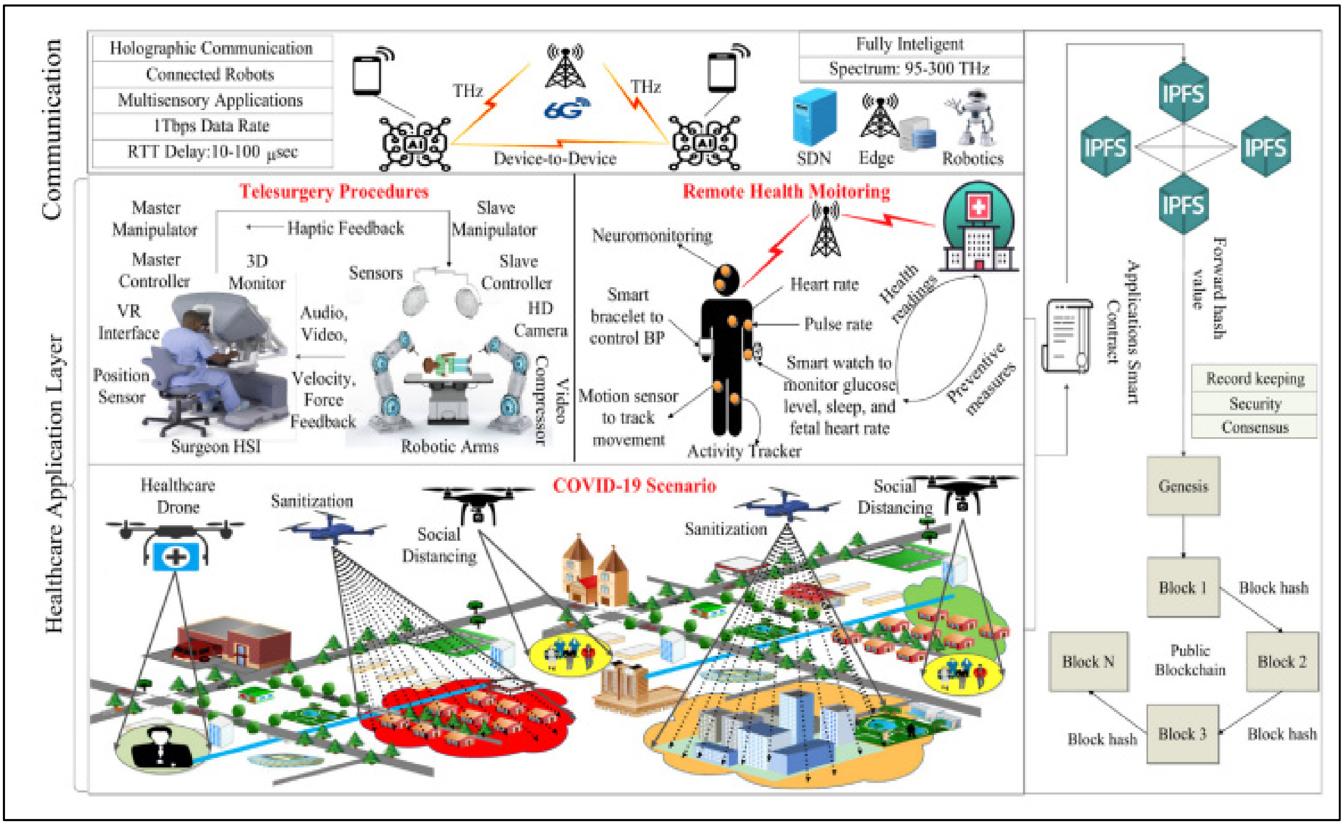

Figure 2. Blockchain-based 6G environment [11].

3. Results and Discussion

3.1. Identified Key Technologies of IoT for Energy-Efficient 6G in Smart Cities

The industrial revolution witnessed in the 18th century revolutionized cities around the globe. The research and markets [4] articulated that smart cities were built to enhance connectivity; however, the contemporary connection facilitations are unable to fulfill the demand of smart cities. Allam et al. [12] discussed the phrase '15-Minute City', referring to the smart urbanization in a post-pandemic era that offers better living standards and improved urban health facilities. The '15 Minute City' could only be made possible by identifying IoT key technologies related to 6G wireless communication in smart cities. However, no holistic study was found in the literature that provided a systematic review of key IoT technologies for 6G in smart cities [13]. Therefore, the current research fills this gap by systematically reviewing 60 peer-reviewed published articles. Ranger [2] proclaimed that IoT infrastructure is expected to reach a billion devices, dependent on connectivity. However, the connectivity provided by 2G–5G is not enough to meet the high demands for IoT devices, especially in smart cities. Therefore, it is highly significant to identify the key IoT technologies for 6G in smart cities that can be used to fulfill the high connectivity needs.

Machine learning and self-organization strategies can considerably improve the network level of 6G communication. 6G will not rely on typical AI operations but will instead require a collaborative AI that is capable of truly revolutionizing the world. According to Mohsan et al. [14], a new kind of communication should have real-time intelligence combined with extremely low latency. As a result, quantum communication technology will be required for the 6G network. Quantum communication has the potential to greatly improve the network's reliability and security. Zhang et al.'s [15] research has shed new light on quantum communication. This technology is, thus, very effective for IoT systems, as it can ensure that the data are processed and communicated whenever required. Additionally, through the use of 6G technology in IoT, big data can be handled with great efficiency. Moreover, high security and instant communication can be obtained using a model of direct transmission, carried out using a quantum channel. This sort of communication is also tied to the blockchain, which is a popular 6G communication technology. The blockchain, which is a combination of network decentralisation and general ledger technology, will be a crucial technology in 6G applications [16].

Blockchain, according to the researchers, is the most disruptive sort of technology, capable of enabling and ensuring the seamless operation of the 6G network. Intelligent resource management is one of the characteristics that blockchains can provide to 6G [17]. Spectrum sharing, orchestration, and decentralised operations, according to the researchers, cannot be made compatible with the current communication infrastructure. VLC is another sort of technology that cannot be overlooked when it comes to 6G. VLC transmits and receives data using visible light [18]. It belongs to the optical wireless communication category and can carry data at frequencies between 400 and 750 THz. The technology's capacity to transmit a large volume of data without major time delays is why it is considered a prerequisite for 6G. Given these characteristics, it is deemed necessary for 6G development to proceed without considering VLC. All these 6G technologies and features add various benefits to the IoT system, which can become highly competitive and optimized based on their speed and bandwidth.

The identified key technologies include quantum communication, blockchain, visible light communication (VLC), 6G BCI, symbiotic radio, and many others. This contradicts the research and markets' [4] findings of limited IoT technologies, as discussed in the previous literature. Zhao et al. [3] proposed that a comprehensive set of IoT key technologies for 6G wireless communication in smart cities is present in the literature. The authors shed light on cell-free massive MIMO technology, referred to as a device that does not centrically attach to any device; instead, they all serve the bases coherently. The IoT devices, i.e., massive cell-free MIMO, can tackle the low communication at the edge of the cell by using 6G in smart cities. In a similar context, Zhang et al. [19] invented the IoT key technology, such as the simultaneous wireless information and power transfer used in smart cities, incorporating the feature of utilizing 6G connectivity. The device is battery-free, and is pretty helpful in providing the fastest communication to members. In addition, Han et al. [20] shed light on the importance of an IoT that can provide internet for everything in the smart city. The authors proposed an intelligent hybrid random access scheme for smart cities that can serve as the IoT technology for 6G in smart cities [21–23]. Therefore, it is not wrong to articulate that the literature provided a holistic set of technologies invented by different scholars. However, a study that incorporates a systematic review of all these invented IoT key technologies for 6G in smart cities is lacking.

According to Kohli et al. [24], there are numerous technologies, such as 6G wireless communication in smart cities, that comprise a brain–computer interface. Since this is one of these emerging technologies, it used human consciousness more than external sources for better interaction. Based on the signals and information that monitor and control machines using sensible wearable headsets and devices, the 6G brain–computer interface (BCI) comprises five datasets, comprising features of human senses that are used for human interaction with the machine [24].

On the other hand, Liang et al. [25] claim that smart cities use symbiotic ration techniques to form cognitive radio (CR) and ambient backscattering communications (AmBC) for enhanced communication across the smart cities. Another technology, such as Reconfigurable Intelligent Surfaces (RIS), is used for the indoor windows of buildings located in smart cities. Ideally, the building receives the signals without interference, and communication among people is easily facilitated [26]. Simultaneous Wireless Information and Power Transfer (SWIPT) is used in smart cities with 6G wireless connectivity to increase communication among members. Typically, this technology enables sensors to use wireless connections for power transfer; therefore, battery-free devices are required in 6G networks [19]. Similarly, the Space–Air–Ground–Sea Integrated Network (SAGSIN) is also used in 6G wireless communication, mainly for global coverage. Using 6G wireless communication, the SAGSIN is formed, which can be helpful in communication in the sky

(10,000 km) and 20 nautical miles for the sea. The biggest advantage of employing SAGSIN is in its integrating air, land and sea to control traffic and communicate with users [27].

The previous literature demonstrated that scholars invented different IoT key technologies for 6G in smart cities. According to Khan et al. [16], blockchain is the key technology used when applying 6G. The rationale is that blockchain provides a transparent and trustful decentralized network that ensures users' data security in the 6G network [28]. As per Sodhro et al. [29], the combination of 6G and blockchain in smart cities could be made possible by using key technologies such as AI, RIS, and TeraHertz Communication (THz). Kumari et al. [11] formed a 6G architecture, as illustrated in Figure 2, which shows that IoT is used for various applications in smart cities, from monitoring traffic signals to managing emergency vehicle services.

As shown in Figure 2, the IoT- and blockchain-integrated system in smart cities may be useful in delivering flexible, secure and reliable communication to the users. This 6G environment comprises three layers, including an (i) application layer, (ii) communication layer and (iii) blockchain layer. Similarly, Hewa et al. [17] discussed the blockchain as a powerful technology that can support and ensure the smooth working of 6G. The authors posited that the current telecommunication infrastructure could not support virtual reality massive Machine Type Communication (mMTC). These technologies require blockchain and 6G to perform smart city operations effectively. Blockchain is significantly essential to IoT security. Therefore, the amalgamation of blockchain, IoT and 6G can allow smart cities to take advantage of the faster and safer connectivity. Moreover, Chi et al. [18] discussed the use of VLC in 6G. The authors propounded that the use VLC in 6G facilitates high transmission service through offline and real-time processing. The two types of VLC devices include PureLiFi and ByteLight and two light sources: LED and laser diode (LD). However, the main disadvantage of LED VLC is its limited bandwidth, which is compensated by LD. Hence, blockchain and VLC, as IoT devices, are related to 6G's implication in smart cities.

The emergence of COVID-19 transformed the lives of human beings. Imoize et al. [26] articulated that COVID-19 brought a new normal, working from the home, for people around the globe [30]. However, the 5G wireless communication network is unable to fulfill people's connectivity demands. Therefore, the authors discussed RIS, Ambient Backscatter Communication (ABC) system, UAVs, CubeSats, and others, which can be used as IoT key technologies for 6G in smart cities to fulfill the post-pandemic connectivity needs. Liang et al. [25] shed light on the ABC system and declared it to be an efficient communication tool. The device improves overall transmission because it forms a backscattering link, forming an effective and advanced communication system. In addition, Kohli et al. [24] posited that 6G BCI is an emerging device used to control or support sensible wearable headsets and embedded devices. Moreover, Khan et al. [31] discussed the use of RIS technologies. The systematic research analysis depicts that RIS technologies with AI, IoT, and blockchain can revolutionize communication network dynamics. Hence, IoT devices with 6G help people to fulfill their connectivity needs after humanitarian crises, i.e., COVID-19. The idea that using such devices in smart cities can benefit humanity is elaborated in the subheading below.

3.2. Applications Key IoT Technologies for Energy-Efficient 6G in Smart Cities

The implications of using 6G in key IoT technologies such as blockchain, VLC, and others rely on their main performance metrics. Mohsan et al. [14] proclaimed that the implementation of 6G wireless communication depends on specific performance metrics. These performance metrics include mobility, energy and spectrum efficiency, throughput, latency, and reliability. The devices and structures tried to meet such standards to implement 6G through IoT devices in smart cities. Ghorbani et al. [31] proposed that the application of 6G and IoT devices ensures unlimited networking possibilities for people in smart cities. According to Upadhyaya et al. [32], the number of smart IoT devices could reach up to fifty, making people lives easier. The application of IoT devices for 6G in smart cities provides a 100 Gbps data rate, <0.1 ms latency rate, up to 1000 km/h mobility rate, 100 bps/Hz spectral efficiency, and 1000 GHz frequency. Moreover, Kamruzzaman [33] discussed the implication of lightweight security modules such as 6G and IoT devices, which can improve the working of smart cities. As per the authors, Smart City Networking Model using Lightweight Security Module (SCNM-LSM) improves smart city living. The application of 6G in IoT devices facilitates e-health, intelligent transportation system, managing energy resources, and networking modeling [34–36]. This depicts that the implication of IoT devices for 6G in smart cities enhances the connectivity rate, which enables people to enjoy unlimited networking possibilities during a post-pandemic situation.

The application of IoT devices in 6G in smart cities can produce incredible benefits. Saad et al. [36] articulated that 6G wireless communication with the help of IoT devices helps to create super-smart cities. The rationale is that 6G connectivity enhances the communication and transmission rate, providing premium-quality features to smart city residents. However, Ghorbani et al. [31] claimed that the implementation of 6G through IoT devices in a smart city can give rise to data security risks, psychological abuse, cyber risks, and others. In contrast, Tariq et al. [37] articulated that the application of AI in 6G can help to control the system's security risks [38]. The collaboration of AI and 6G transform the healthcare system by providing precise medical solutions and health-monitoring. This allows for healthcare workers, patients, and hospital management to keep the details secure, enhancing their benefits to the community. In addition, Al-Turjman and Lemayian [39] discussed the intelligent transport system (ITS) that is implemented in smart cities, facilitating the use of smart logistics. The authors discussed the United Nations Population Funds' predictions that 60% of the world population in the next ten years will move to smart cities that imply the use of IoT devices with 6G [40,41]. Hence, the pattern of 6G being implemented through IoT devices has started in smart cities, which are the future of the global population.

It has demonstrated that 6G application through IoT devices can help people to receive unlimited benefits. This can be seen in Allam et al. [10] 's example, presenting a '15 Minute City' through 6G and IoT devices. According to Allam et al. [10], the '15 Minute City' is the new urban planning model presented by Franco-Colombian scientists, using intelligent devices with the fastest connectivity rate to enhance people's livelihood. As per the authors, the '15 Minute City' is the true example of applying 6G and IoT devices to build a super-smart city. In addition, Kumari et al. [11] highlighted the amalgamation of IoT, blockchain, and 6G in the smart city. As per the authors, the application of 6G wireless communication in the smart city can address latency and reliability issues. Blockchain technology can handle security and privacy risks, and IoT facilities play a significant role in security, privacy, latency, and reliability [42]. The authors provided different application examples, including ITS, smart grids, smart healthcare facilities and others. Hence, the application of 6G with IoT devices can help to formulate the '15 Minute City', ITS, smart grid, smart healthcare facilities and others.

Smart cities address people's issues and could lead to a revolution in people's lives. The application of 6G can facilitate connected robotics and autonomous systems, such as drone-delivery UAV systems. The drone-delivery UAV system can ensure the timely delivery of packages. In addition, the implication of 6G through IoT devices in smart cities can provide the necessary facilities for people to use self-driving cars that protect them from traffic accidents and hustle [42]. Moreover, Chimmanee and Jantavongso [43] have provided an example of the "Bangkok Metropolitan Region" (BMR) that entails a region known as an "Industrial Town", built as a smart and sustainable city. The industrial town ensures the deployment of the 6G facility with IoT devices, which can provide the fastest connectivity. The authors applied the practical mobile planning and optimization framework. They found that the implication of 6G through IoT devices in industrial towns allows for people to fulfill their techno-economic opportunities by focusing on sustainable goals. Moreover, Ibba et al. [44] discussed the use of IoT devices to create a better environment. The sensors from devices produce digital measurements that improve people's quality of life in every smart city. The authors shared an example of the 'CitySense System', which characterizes the quantities of different environmental elements such as carbon dioxide, methane, temperature, air, humidity, and light. The measured quantities regarding environmental pollution concerns provide solutions to maintain the environment of smart cities and ensure a healthy lifestyle for residents. In the context of smart cities, 6G wireless communication is extremely useful when building a super-smart society. The superior and premium features of 6G, enhancing communication and interaction in terms of quality of life, are remarkable when applied in smart cities [45]. AI-based Machine-to-Machine (M2M) communication is used to monitor environmental activities, ensure automation in super-smart societies and improve quality of life. Another application of smart cities is using extended reality and augmented reality (AR), virtual reality (VR) and mixed reality (MR) to form features, using 3D objects for effective communication. AR allows for individuals to interact with the physical world based on the 3D landscape. On the other hand, MR forms a real and virtual atmosphere, where the interaction takes place in real time. This is why MR is also recognized as a hybrid application of the technology, which creates a 3D environment for users [46]. Figure 3 shows that Nguyen et al. [9] have shown that fog computing is a real-time application, minimising time, computational cost, energy and storage issues when IoT is implemented in smart cities.

Fog computing is a cloud-computing combination of routers, storage data and computers with end-users in close proximity. Moreover, connected robotics and autonomous systems are also an application of the 6G wireless communication network. The 6G could be useful in the deployment of connected robots and autonomous systems, such as drone-delivery UAV systems. The 6G communication system employing robotics and autonomous systems promotes self-driving cars and improves traffic and driving patterns using the sensors. A wide range of sensors is used in 6G wireless communication, including Light Detection and Ranging (LiDAR), radar GPS, sonar and odometry and inertial measurement units. When using 6G wireless communication such as UAV, there is a system communication between the ground-based controller and systems communications [42]. Furthermore, the AI application of the 6G wireless communication can be useful in providing smart healthcare systems with health monitoring and precision medical treatment. It also supports privacy and a high-level protection and support system for healthcare workers, professionals and patients, thus maximizing the advantages of its application [37].

6G wireless communication can also provide haptic communication, as it is a nonverbal communication medium that employs the sense of touch. This is extremely useful for remote users, as they can experience haptic communication and interaction in the real world. The superior features of the 6G application are useful in haptic communication in smart cities among the members and individuals. Similarly, a 6G wireless communication network can be applied in industry for manufacturing and automation purposes. By providing full automation to provide secure communication and interaction mediums, 6G wireless communication can ensure high-data-quality transfer that is nearly error-free. Another significant aspect of employing a 6G system is data transfer without any data loss when transmitted and received by the end-user [42]. Hence, the application of IoT devices is revolutionizing the people's lives through the new state-of-the-art, i.e., 6G wireless communication in smart cities.

3.3. Key IoT Trends for Energy-Efficient 6G in Smart Cities

IoT has become highly popular globally, due to its ability to automate processes and make processes smarter. IoT has several applications that are very beneficial to the entire globe. One major application of IoT includes smart cities [47,48]. Therefore, a large amount of research and development is being conducted in this area to enhance the application and use of IoT in smart cities. One of the major issues faced by previous technologies in the application of IoT and smart cities is that they are unable to handle and process the large amount of data that are produced [6,49]. However, 6G technology can enhance the processing and communication of IoT systems by making them more efficient and faster. Therefore, the current research paper aims to highlight the key trends in the (IoT) for energy-efficient 6G wireless communication in smart cities.

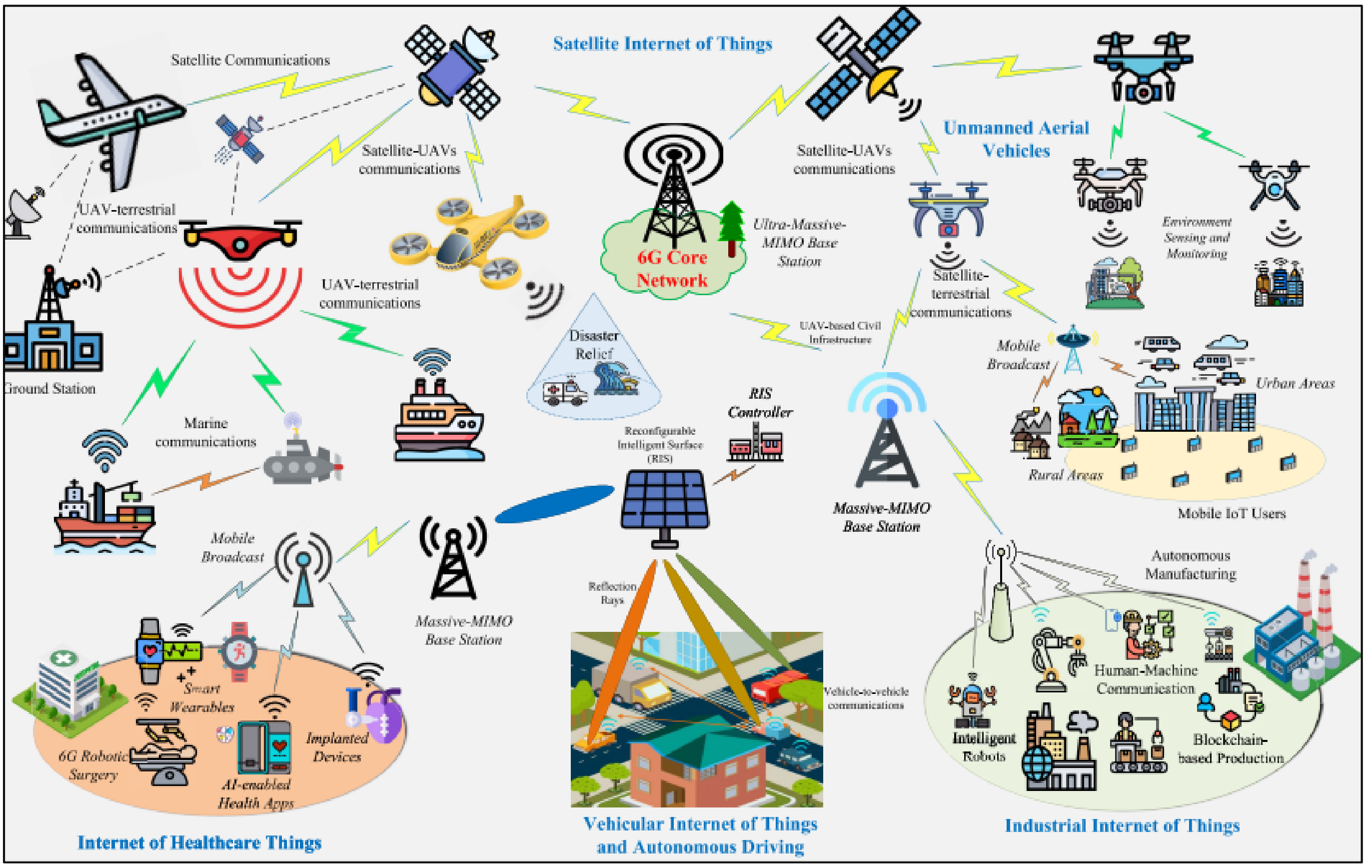

Figure 3. Smart cities and IoT devices. Source: Nguyen et al. [9].

A new trend that has been noted in the area of IoT is Holographic Connectivity. Technologies based on holography can enable the integration of various technologies and communication between devices that could not previously be connected, thanks to the network speed of 6G connectivity [7,49]. It may also deliver a real-time simulation experience and provide consumers with an amazing naked-eye simulation experience. This trend, like 6G, is highly underdeveloped and only exists in principle. However, considering the current rate of technological advancements and the present interest displayed by nations such as China and the United States in the development of AR holographic technology, it is only a matter of time before this technology becomes a reality [50,51]. Lu and Zheng [50] proposed that 6G can be referred to as holographic connectivity, intelligent connectivity, deep connectivity, and ubiquitous connectivity. 5G is the early stage of commercialization network connectivity function, which is not sustainable for the current era. Therefore, the future application of 6G technology can further enhance the IoT systems in smart cities through large-scale applications, as data transmission and processing speed will increase.

Other technological advancements have made intelligent monitoring devices in IoT, such as integrated circuits and wireless communications, smaller, lighter, and more energy-efficient [52]. In addition, another key area in IoT systems and 6G technology is data security. Wang et al. [7] and Chen and Okada [52] noted that the use of 6G technology could lead to more effective security solutions. The radio latency of a 6G network may be lowered to 0.1 ms, which is significantly lower than that of a 5G network. However, there are still security vulnerabilities in the 6G network, including in authentication, encryption, and communication [53]. Furthermore, a 6G wireless communication system is likely to be effective in reducing heterogeneous hardware restrictions in the coming years. As per [42] and [54], 6G connectivity will transform individual interactions in smart cities. Access points and mobile terminals that are not part of the hardware configuration may be required for quick and error-free communication. Additionally, the use of MIMO techniques can lead to the advancement of 6G architecture, making it more secure and effective [55,56]. Borges et al. [57] articulated that MIMO communication systems are based on the antenna array at the receiver and transmitter side, which can also be used in 5G technology. The antenna array's presence made the MIMO communication system a high-speed transmission technology with a minimum quality level. Therefore, the use of a 6G communication system makes MIMO as energy efficient, high-speed communication tool with the assurance of high-quality level transmission. Hence, the trends in 6G and IoT development show that, in the future, it is likely that smart cities will be safer in terms of privacy and confidentiality as the systems will be able to transfer and store data using strong security protocols [58]. This would also lead to an increase in the trust of the users and public, leading to the enhanced applicability of IoT systems based on 6G technology.

Moreover, it is also noted that the collaborative use of 6G technology and IoT system leads to the development of diverse architectures with the potential to gather large amounts of data. New driving trends, such as Smart Reflective Surfaces and Environments, may emerge as a result of the 6G wireless system. The smart reflecting surfaces, according to this concept, serve as walls, highways, entrances, and complete structures. When driving, this also aids in maintaining a clear line of sight and obtaining high-quality signals [26,59]. As a consequence, when a 6G communication network is used in the system, there will be little to no risk of loss or accidents on the roadways. Zhihan et al. [59] and Nguyen et al. [9] noted that the use of 6G technology could lead to the large-scale application of IoT systems with technologies such as AI and big data analytics. Through the development of these systems, IoT systems in smart cities could be developed to provide a more convenient and safer transportation infrastructure. Additionally, these systems are likely to enhance the security of smart cities, making people more comfortable. Another critical feature of 6G technology is AI-based computer vision using deep learning, which was recently worked on in many applications [60]. As per Mahmoud et al. [22] and Mucchi et al. [61], in smart cities, 6G wireless connectivity might be a new trend in wireless energy transfer and collection. Energy transfer for harvesting may be accomplished in smart cities utilizing 6G cellular networks, according to this approach. A highly positive effect on the environment can be noted through the development of such trends, as they will reduce the large number of carbon footprints. Hence, these benefits of 6G technology and IoT in smart cities are motivating researchers to find convenient, cost-effective, and efficient solutions that can easily be employed to enhance the infrastructure of smart cities [62,63].

Moreover, in the coming years, it is expected that a 6G wireless communication system will be useful in minimizing the heterogeneous hardware constraints. This implies that the 6G communication would revolutionize interactions among individuals in smart cities. Access points and mobile terminals may be needed for fast and error-free communication that will be entirely different from the hardware setting [42]. It is also expected that MIMO techniques can further be upgraded in the 6G architecture for advanced-level communication. A 6G wireless system may also give rise to new driving trends, such as Smart Reflective Surfaces and Environments. It even helps to maintain a line of sight and obtain high-quality signals when driving [26]. As a result, there would be minimal to no chances of loss or accidents on the roads when a 6G communication network is employed in the system. Likewise, Zhao et al. [63] claims that there is an emerging trend of 6G communication in the network layer. Within this domain, there is a traffic and mobility prediction that allows for smart cities to improve prediction accuracy in traffic. Moreover, 6G may even promote mobility and handover management intelligent network management, which could minimize accidents. According to Ho et al. [62], there is another emerging trend of employing 6G in the smart grid system, so that a number of IoT devices can be connected to ensure real-time remote monitoring of the system. Table 2 provides a comparison between the technologies being discussed with respect to smart cities and wireless communication.

Table 2. Comparison between the technologies with respect to smart cities and wireless communication.

Technologies	Application	Trend	Challenges
Quantum communication	The application of quantum communication with respect to wireless communication and smart cities protects information channels against eavesdropping by means of using quantum cryptography [61].	Among the key trends relating to quantum communication with respect to wireless communication and smart cities is the security of sensitive information, as the technology allows for strong encryption protocols to protect the communication messages [64]. Quantum communication has the ability to transform multiple markets, including many tech giants and startups, due to its unique abilities. Moreover, quantum communication is also expected to facilitate long-distance communication such as transmission across ocean, as the technology relies on satellite for the transfer of information [62].	The key challenges include maintaining a quantum communication network, transferring of quantum states, a secure infrastructure and encryption, along with the creation of public trust [63].
Blockchain	Blockchain technology can facilitate the interconnection of cities through its vertical services such as accessibility, mobility, transversal system and security benefits.	The technology has the ability to empower smart cities by allowing for data exchange with a higher degree of transparency and reliability without the need for a centralized administrator.	The challenges include a lack of awareness relating to the usage and working of the technology, which results in a waste of resources during the exploration process.
Visible light communication (VLC)	VLC is a wireless communication method, which allows for the transmission of information at a high speed with visible light. The information acquired through this technology is transmitted by modulating the intensity of light from the light source.	The key trends in VLC in smart cities include traffic management by facilitating vehicle-to-vehicle and vehicle-to-infrastructure communication. Moreover, streetlights that communicate with pedestrians' VLC-enabled smart phone devices can help to regulate traffic. The technology leads to possibilities for hybrid communication.	The key challenges in the technology include flicker, which is a major problem as light travelling at such a high speed can cause damage to the human eye. For indoor environments, dimming also is a challenge as the light needs to be adjusted as per the requirements.
6G BCI	The 6G applications include optical wireless communication, wireless power transfer and 3D networking. In addition, the technology can facilitate unmanned aerial vehicles, along with the advanced usage of AI in the smart cities.	Among the key trend of the technology include improved privacy in communication and transmission of information, improvement in global health, improved transportation, logistic facilities and security, all of which contribute to the building of smart cities.	The challenges relating to 6G communication include the attainment of a cost-effective approach for network deployment and expansion, data privacy enforcement, security concerns and the challenge of reducing the price of mobile communications.
Symbiotic radio	Symbiotic radio technology is a batteryless smart device that allows for the sharing of data with corresponding access points by employing Wi-Fi TV signals through backscattering waves.		The key challenges of the technology include the establishment of an accurate channel model to capture the essential behavior of backscattering channel and the management of the limited resources required to fulfill the wireless communication requirements. Moreover, privacy and security are also concerns in the wireless communication system; since the primary and secondary transmissions in symbiotic radio technology are connected, if an attacker disrupts primary transmission, the probability of affecting the secondary transmission becomes increasingly easy.

4. Conclusions

This study showed that IoT, along with energy-efficient 6G technology, has the potential to make smart cities more efficient and effective. The use of 6G by IoT devices can transform smart cities into super-smart cities. As a result, this research focused on IoT technologies, applications, and trends for energy-efficient 6G wireless communication in smart cities. The three goals emphasize the most important IoT technologies, applications, and trends in smart cities. The systematic review aided in accomplishing the study goal by analyzing 20 papers taken from online databases and Google Scholar, published between 2015 and 2021. The most relevant and reliable papers were selected and reviewed systematically. The findings of the paper noted that quantum communication, blockchain, VLC, 6G BCI, symbiotic radio, and other technologies are essential technologies. Through the use of these technologies, IoT systems in smart cities can work efficiently to provide high-quality services of traffic management, security, surveillance, etc. In addition to this, this study also examined the different applications of IoT systems based on 6G technology in smart cities. These applications include the 15 Minute City, Industrial Town, and ITS. Furthermore, more applications of IoT and 6G are likely to be researched and developed in the future, considering the high pace at which they have been adopted by researchers and experts in this field. Besides this, the trends in research and development in IoT and 6G technology show that future smart cities will be more efficient and effective, as they will be able to handle data at great speeds. These systems are likely to solve sustainability problems and make smart cities more environmentally friendly. In addition, the recent trends show the researchers' significant focus on security and data transmission speed and the performance of the systems, which is likely to make IoT and energy-efficient 6G-based smart cities highly effective. The application of IoT devices to 6G in smart cities provides a 100 Gbps data rate, <0.1 ms latency rate, up to 1000 km/h mobility rate, 100 bps/Hz spectral efficiency, and 1000 GHz frequency. This is most promising in resolving the issues of energy inefficiency and other concerns in classical communication networks. Conclusively, the use of energy-efficient 6G in smart cities via IoT devices is promising and is likely to solve various problems that are encountered by existing smart city systems.

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Appendix A

The table below, Table A1, shows the results of the systematic literature review conducted in the study.

Table A1. Results of systematic literature reviews.

Serial No.	Author Name	Title	Year	Findings and Results
		Key Technologies		
1	Mohsan et al.	6G: Envisioning The Key Technologies, Applications and Challenges	2020	Real-time intelligence twinned with extremely low latency is enhancing communication through the 6G network. Quantum communication can also increase the reliability of communication.
2	Zhang et al.	Quantum Secure Direct Communication With Quantum Memory	2017	A direct communication model employing a quantum channel is useful for instant communication through a 6G network, such as blockchain technology.
3	Hewa et al.	The Role of Blockchain in 6G: Challenges, Opportunities and Research Directions	2020	Blockchain is a disruptive kind of technology that allows for 6G intelligent resource management for smooth functioning.
4	Chi et al.	Visible Light Communication in 6G: Advances, Challenges, and Prospects	2020	Visible Light Communication (VLC) enhances data transmission through the 6G network. With the ability to transfer data ranging up to 400 and 800 THz, VLC is a time-efficient technology for smart cities.

Table A1. *Cont.*

Serial No.	Author Name	Title	Year	Findings and Results
5	Kohli et al.	A Review of Virtual Reality and Augmented Reality Use-Cases of Brain-Computer Interface Based Applications For Smart Cities	2022	The brain–computer interface (BCI) allows for the exchange of information and signals through different controlling machines such as sensible wearable headsets and embedded devices.
6	Liang et al.	Symbiotic Radio: Cognitive Backscattering Communications For Future Wireless Networks	2020	Symbiotic radio technology is effective for smooth communication processes as it employs backscattering link signals for advanced level communication and interaction in smart cities.
7	Imoize et al.	6G Enabled Smart Infrastructure For A Sustainable Society: Opportunities, Challenges, and Research Roadmap	2021	Reconfigurable Intelligent Surface (RIS) is a technology that is used in the doors and windows of buildings in smart cities as it shares signals without any interference among individuals.
8	Zhao et al.	A Comprehensive Survey of 6G Wireless Communications	2020	MIMO technology in 6G wireless connection can operate without cells and provides spectral efficiency in a communication network.
9	Zhang et al.	Wireless Information and Power Transfer: From Scientific Hypothesis to Engineering Practice	2015	Simultaneous Wireless Information and Power Transfer (SWIPT), technology is able to detect sensors using wireless connections to improve the communication network.
10	Giordani and Zorzi	Satellite Communication At Millimeter Waves: A Key Enabler of The 6G Era	2020	the Space–Air–Ground–Sea Integrated Network (SAGSIN) integrates air, land and sea to control traffic and enhance communication.
11	Nguyen et al.	6G Internet of Things: A Comprehensive Survey	2021	The use of 6G technology enables the integration of various IoT technologies, such as edge intelligence, space–air–ground–underwater communications, reconfigurable intelligent surfaces, massive ultra-reliable, Terahertz communications, low-latency communications, and blockchain.
12	Allam et al.	Fundamentals of Smart Cities	2022	IoT-based 6G systems use technologies such as RFID and wireless sensor networks to process and transfer data at a high speed, which ensures their high performance.
		Key Applications		
1	Saad et al.	A Vision of 6G Wireless Systems: Applications, Trends, Technologies, and Open Research Problems	2019	6G wireless communication can be employed in smart cities to develop a hybrid model of technology in a 3D setting.
2	Chowdhury et al.	6G Wireless Communication Systems: Applications, Requirements, Technologies, Challenges, and Research Directions	2020	6G wireless communication can be used for LiDAR, radar GPS, sonar and odometry and inertial measurement units when autonomous driving patterns are promoted. 6G wireless communication may improve ground-based controller communication when employed in robotics and the autonomous driving of vehicles. Moreover, the 6G wireless communication network can be used in the manufacturing industry with a high-data-quality transfer rate, with minimal chances of error. The 6G system also prevents data loss and ensures the safe transmission of data from the sender to the receiver. 6G is also applicable in haptic communication in smart cities.
3	Tariq et al.	A Speculative Study on 6G	2020	A smart healthcare system includes 6G precision medical treatment, providing high-level protection and supporting healthcare workers.

Table A1. *Cont.*

Serial No.	Author Name	Title	Year	Findings and Results
4	Xiaohu et al.	6G Internet of Things: A Comprehensive Survey	2020	6G has high potential in the following IoT applications: healthcare IoT, vehicular IoT autonomous driving, unmanned aerial vehicles, satellite IoT, and industrial IoT.
5	Atitallah et al.	Leveraging Deep Learning and Iot Big Data Analytics to Support The Smart Cities Development: Review and Future Directions	2020	The application of IoT based on 6G has the potential to handle big datasets and integrate cloud-based technologies to provide various services to smart cities.
6	Ye et al.	Big Data Analysis Technology For Electric Vehicle Networks in Smart Cities	2020	The application of 6G and IoT has enhanced the application of electric vehicles and autonomous cars.
7	Liu et al.	An Overview of Key Technologies and Challenges of 6G	2021	The use of 6G in IoT has widened the scope of applications, as various advanced technologies, such as VR and AR, can be implemented easily with great speed and security.
8	Ho et al.	Next-Generation Wireless Solutions For The Smart Factory, Smart Vehicles, The Smart Grid and Smart Cities	2019	IoT based on 6G has enhanced the application of smart grids with the potential to save various power losses and make energy systems more efficient.
9	Al-Turjman and Lemayian	Intelligence, Security, and Vehicular Sensor Networks in The Internet of Things (Iot)-Enabled Smart-Cities: An Overview	2020	IoT smart cities have taken the communication of information to another level due to the use of 6G, as it has very high speeds and ensures the fast travel of large data.
10	Wang et al.	Security and Privacy in 6G Networks: New Areas and New Challenges	2020	The use of 6G in IoT has also enhanced security applications, making smart cities safe from privacy and data breaches. This ensures large-scale applications and easy adoption by the public.
		Trends		
1	Kamruzzaman	6G wireless communication assisted security management using cloud edge computing	2022	Security management is the process of identifying a company's assets (such as people, buildings, equipment, systems, and information assets) and then developing, documenting, and implementing policies and procedures to secure those assets. Meanwhile, artificial intelligence (AI) applications are flourishing thanks to advances in deep learning and numerous hardware architecture improvements based on cloud edge computing (CEC) issues are associated with the Internet of Things (IoT), including inadequate security measures, user ignorance, and the dreaded active monitoring.
2	Wang et al.	Security and Privacy in 6G Networks: New Areas and New Challenges	2020	6G is facilitating holographic connectivity, which implies that each and every device is connected to the network. Based on this integration of technologies, holographic connectivity may provide a strong connection between devices with a real-time simulation experience. In countries such as China and the US, augmented reality (AR) holographic technology with security features may be seen in the future. Thus, holographic technology in 6G may emerge as a new trend due to the security and privacy of the system.

Table A1. *Cont.*

Serial No.	Author Name	Title	Year	Findings and Results
3	Chowdhury et al.	6G Wireless Communication Systems: Applications, Requirements, Technologies, Challenges, and Research Directions	2020	6G communication systems may create access points and mobile terminals for fast and error-free communication. This can be helpful in reducing heterogeneous hardware constraints. MIMO techniques may advance the 6G architecture in the future.
4	Imoize et al.	6G Enabled Smart Infrastructure For a Sustainable Society: Opportunities, Challenges, and Research Roadmap	2021	6G wireless communication may be employed in smart reflective surfaces and environments in smart cities. This trend may increase when smart reflective surfaces are used in walls, roads and doors.
5	Luo	Machine Learning For Future Wireless Communications	2020	6G may help in network layers such as traffic and mobility prediction in smart cities, prediction and accuracy in traffic, promoting mobility and handover management to reduce the chance of accidents.
6	Mahmoud et al.	A Comprehensive Survey on Technologies, Applications, Challenges, and Research Problems	2021	6G wireless communication is a new trend in wireless energy transfer and harvesting in smart cities, allowing for energy transmission for harvesting to be possible in smart cities.
7	Sher et al.	An Overview of Key Technologies and Challenges of 6G	2021	Virtual reality (VR), Terahertz (THz) communication, visible light communication, radio stripes, quantum networks communication, and large intelligent surface (IRS) are the six different technologies that can be useful for 6G wireless communication.
8	Ji et al.	Amalgamation of Blockchain and Iot For Smart Cities Underlying 6G Communication: A Comprehensive Review	2021	The use IoT and 6G together increases efficiency in smart cities, but a single point of failure can negatively impact the lives of individuals. Therefore, blockchain can be effective in overcoming the challenges of implementing IoT and 6G in smart cities.
9	Elmeadawy and Shubair	Fundamentals of Smart Cities	2019	Smart cities include wireless sensor networks, IoT, RFID and 6G to increase intelligent urban facilities.
10	Han et al.	Role of Iot-Cloud Ecosystem in Smart Cities: Review and Challenges	2020	There is a limited computational capacity of end-devices in IoT infrastructure in smart cities. However, the future of smart cities may require both IoT and cloud infrastructure for better activities.
13	Fang et al.	Intelligence, Security, and Vehicular Sensor Networks in The Internet of Things (IoT)-Enabled Smart-Cities: An Overview	2021	The IoT smart cities paradigm is based on different design features such as reliability and robustness. However, 6G communication networks in smart cities may give rise to security concerns that must be addressed, and one way of doing this is to develop security standards for IoT devices.

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