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Intelligent Connectivity for Smart City Development

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Abstract: The paper presents an overview of the progress of modern information and communication technologies (ICT), which are necessary for the development of smart cities (SC). A focus was given to the explanation of the concept of Intelligent Connectivity (ICon) that includes the convergence of key technological trends: mobile networks of the fifth generation (5G), Internet of Things (IoT), Artificial Intelligence systems (AI) and Cloud Computing (CC). The 5G smart networks are expected to enable the integration of Internet of connected objects (AIoT) by supporting intelligent connectivity ICon and becomes a key prerequisite for an advanced Smart City (SC) infrastructure. The intelligent connectivity for SC development should enable the integration of technologies with sensor networking, information processing and real-time control to efficiently utilize infrastructure.

Keywords: Smart City; Intelligent Connectivity; 5G, IoT; Artificial Intelligence

1 INTRODUCTION

Smart city (SC) is an innovative solution for today's urban areas that utilize advanced digital technologies to provide better infrastructure, modernize government services, improve accessibility, accelerate economic growth, and improve sustainability. Opportunities and challenges depend on many different factors, such as the population, location, climate, environment, and area of the city as well as priorities and primary implementations. Currently, numerous smart city developments are ongoing around the world. SC projects have emerged mainly as a result of highly innovative ICT solutions, and additionally, they have started to use new generation wireless networks taking advantage of the Internet of Things (IoT), Big Data (BD) and cloud computing (CC) technologies to establish a smart connectivity in Smart City development [1, 2, 3].

The concept of intelligent connectivity (ICon) includes the convergence of key ICT trends: 5G (fifth generation) mobile networks and AI (Artificial Intelligence) systems. ICon is based on the use of advanced technology for improved communication between devices, systems and users. The goal is a seamless and intuitive user experience and support for new applications and services that were previously not possible. The technological trend is the efficient and reliable connection of devices and systems, as well as new applications and services. ICon systems provide improvements in different aspects of operations and organizations, such as quality of life and infrastructure in the Smart City (SC). SC solutions are developed and implemented in smart environment, smart mobility, smart living and smart people.

Smart environments (SE) are new concepts in developed improved services for the residents of a city, better quality of life for an individual, or more efficient manufacturing for a company [4, 5].

Smart Home (SH) provide a variety of options to interact with others without having to leave the house. The entire home ecosystem, including heating, air conditioning, water, electricity, energy consumption, lighting, entertainment, appliances, household robots, air quality, smoke/gas/leak detection, home access, security, and privacy, can be fully managed and monitored thanks to SH intelligent, connected, automated, and integrated control, computing, and communication system. Although there are many different things and services available today, the markets and solutions are a dispersed. Furthermore, complete smart and automated home solutions that incorporate all necessary components are still relatively lacking. Additionally, standardization and common norms are insufficient, particularly when it comes to data security and privacy. We are still waiting for a significant advancement in smart homes. For technology companies (mobile network operators, vendors, and service providers), this will create new business opportunities to offer plug-and-play solutions that are complete and personalized. Collaboration between tech companies, constructors, and building owners is necessary.

Smart Factory (SF) combines mainstream information, communication, networking, computing, and control technologies and procedures to improve a factory's intelligence, automation, productivity, quality, flexibility, adaptability, and predictability, is still relatively in its beginning. In the new era of smart manufacturing, where the integration of certain mainstream digital technology becomes commonplace and transforms the whole industrial sector, a smart factory is at the centre of Industry 4.0. Numerous advantages are offered by smart factories, including better process monitoring, management, maintenance, and repair; higher manufacturing efficiency; lower manufacturing costs; better quality products; faster production cycles; more robust processes; improved security; better threat and hazard prevention; and innovative production solutions.

Smart society (SS) refers to a concept that uses a wide range of advanced digital technology to improve society at all levels. A smart society is anticipated to provide a range of advantages for people, communities, and the public and private sectors through the use of various technologies. A higher quality of life in terms of better services for living conditions, healthcare, employment, education, social benefits, free-time activities, and public safety are among the potential advantages for people. New commercial prospects, more effective manufacturing, testing, and design processes, lower production, operation, and maintenance costs, and reduced impact on the environment are some of the possible advantages for the private sector.

Smart cities SC connect social infrastructure and physical infrastructure. Investing in ICT infrastructure improves economic growth and quality of life. The main objective is to provide residents with services that increase the effectiveness of daily activities. Assuming a variety of different applications and particular requirements, SCs rely on the sharing of information and large volumes of data.

5G connectivity ecosystem comprises a broad set of technologies, users, companies, products and services that evolve together to meet new requirements and create markets. The ecosystem also includes the regulatory direction, standardization organizations, as well as relevant industry associations. Members make contributions that complement and reinforce the contributions of other members, resulting in a complex integrated system. A systemic approach in creating a technological ecosystem implies observing the complete network and components as an integrated and inter-reliant system. The approach ensures that the various elements work seamlessly together to realize the benefits of 5G technology:

• identifying problems or requirements and forming system requirements, as well as the most promising technological options

• research and development of innovative technologies and the formation of a flexible system architecture supports increased data transfer rates, low latency and massive connectivity of intelligent devices

• ensuring compliance with international standards for the interoperability of various suppliers and service providers

• cooperation with device manufacturers for a diverse and interoperable technological ecosystem

• cooperation with regulatory authorities to resolve legal and political challenges associated with the commercial application of 5G technology

• conducting extensive prototype testing and performance demonstrations, concept validation that ensures reliability, performance and adherence to standards

• adoption of a systemic approach, so that all stakeholders in the 5G technological ecosystem can achieve integrated, efficient and secure cooperation that meets the various requirements of both consumers and companies.

To ensure seamless interoperability between ICT devices, the International Telecommunication Union Telecommunication ITU-T is establishing standards that specify the requirements, frameworks, operations, and management systems for ICT technologies, enabling the development of advanced wireless networks [6-12].

The main goal of this research was to raise awareness of the community about the current state of the smart city SC developments revealing its key future trends. The paper is organized as follows. After an introduction, intelligent connectivity ICon enabling technologies are presented with focus on cloud-driven IoT-based big data BD and 6G enabled the New Smart City. In conclusion, we point out that there is a need for a critical reassessment of the ICT sector for smart cities SCs development.

2 ICon enabling technologies

ICon represents the synergy of smart technologies and communication infrastructure with a goal more efficient services, improvements in user-computer interaction, as well as improvements management and data analytics. The convergence of communication, IoT and AI is an obvious logical one progress in the evolution of these technologies. Data collected by IoT devices and sensors can now be effectively analyzed and contextualized using AI method. The two technological concepts absolutely complement each other, are rapidly developing and they have a vital role in the progress of smart cities and society. Artificial intelligence is the real driving force behind the full potential of ICT (Fig.1).

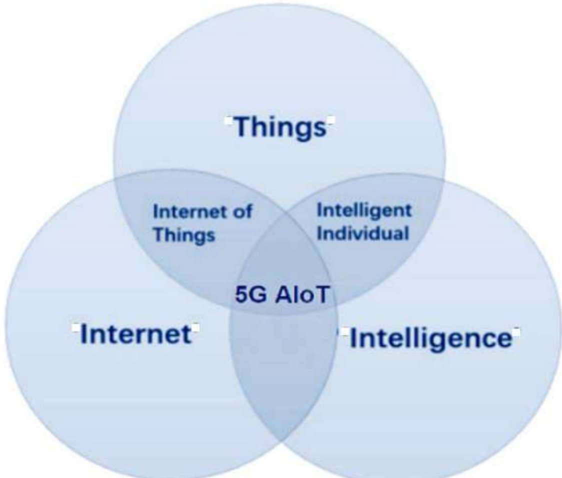

Figure 1 The relationship among 5G, IoT and AI.

Significant features of 5G network connectivity are high data transfer speeds and very low latency. SC systems have been applied in various domains to test the potential of new smart systems while identifying the infrastructure necessary to support future services for a large number of devices. The goal is to develop integrated solutions and new applications for building smart cities and improving the social life of citizens, including economic growth. The IoT is one of the significant ICT technologies to support smart cities SC, along with connectivity, data analytics and artificial intelligence AI. Many countries have launched SC projects of smart cities and large investments in development. Analyzing the advantages and challenges of 5G-IoT technology is crucial for the development of future smart cities.

However, in reality there are still many challenges. The ICon concept encompasses various design principles, industrial standards and development heterogeneous computing platforms and network topologies. A successful smart environments require standardization that includes interoperability, compatibility, and reliability [9, 10, 11].

Connectivity. In order to build smart cities SCs and set the groundwork for more connected future, 5G/6G low latency, and IoT are essential. For systems like energy management, traffic management, and public safety systems to operate seamlessly, high-speed, reliable communication is required. Large volumes of data produced by IoT devices can be efficiently transmit to the faster and more reliable connectivity offered by the 5G and upcoming 6G networks. Because it facilitates rapid actions and real-time decision-making, low latency is especially crucial in SCs. IoT is essential to SCs because it facilitates the deployment of SC systems and provides the data required for data-driven decision-making.

The following use case classes are defined by the joint initiative 5GPPP of the EU ICT industry: highly populated metropolitan areas, broadband access at any location, connected autonomous vehicles, the future smart office, NB-IoT, tactile Internet, and automation. Key KPI indicators that match the performance requirements (in terms of the service's user experience) that the 5G network can provide are established for each unique scenario. Device density in a particular region, mobility, infrastructure topology, traffic type, user data flow, delay, reliability, availability, and communication category are the criteria used by the PPP initiative to categorize fundamental functionality.

Internet of Things. The entities in the development of SCs include sensors, networked devices, machine-to-machine (M2M) communication, and IoT. Internet of Things serves as the foundation for the interconnection of SCs, including public safety, energy, and traffic control systems. The seamless transfer of data between various systems and devices is made possible via M2M communication, which serves as the basis for SCs' effective operation. Sensors and actuators are examples of networked devices that supply the data required for SCs to make data-driven decisions. In particular, sensing is essential to data gathering and analysis because it offers real-time data on a variety of metrics, including ambient conditions, energy consumption, and traffic movement.

Smart city applications based on IoT infrastructure are categorized based on network type, scalability, coverage, flexibility, heterogeneity, reliability and end-user engagement. Applications can be grouped into personal and residential, communal, mobile and business. Utilities include smart energy grid, smart metering/monitoring, water network management and video surveillance. Similarly, mobile applications include intelligent transportation systems and logistics, and traffic management.

The implementation of 5G IoT supports making cities much smarter. Numerous devices are linked to a mobile network with very high speed. An intelligent and controllable environment is made possible by automation, which is embraced by the Internet of connected objects (IoT). It essentially comes down to data management, formatting, and connectivity. Different IoT protocols, data formats, processing, and interfaces are needed for various use cases. Interoperability and open standards are crucial because the Internet of Things does not yet have a global standard. The challenge is that industry initiatives are fragmented and unfocused, and IoT deployments and use cases are unfocused.

The smart city SC has many criteria for IoT applications. IoT, for instance, is anticipated to provide low cost, low power consumption, high quality of service (QoS), extensive coverage, increased flexibility, high security and privacy, ultra-dense implementation, and equipment manufacturer compatibility. To create a completely autonomous environment, IoT implementation relies on a variety of network topologies.

Data. The development of SCs requires the use of data analytics, data management, data storage, and data infrastructure. The amount of data generated is enormous and increasing daily due to the growth of the IoT and the increased use of technology in urban areas. These statistics offer important insights into how a city operates, including public safety, energy use, and traffic flow. Cities can use data analytics to make sense of these data and make data-driven decisions to increase their sustainability and efficiency. An SC infrastructure must have enough data management and storage to guarantee that the generated data are secure and easily accessible for analysis. Since it serves as the basis for all data-related operations, SCs also require a robust data infrastructure. This covers the technology, software, and network needed to handle, store, and analyze large volumes of data. Cities can fully benefit from big data BD and data analytics DA with the proper data infrastructure in place, creating a more intelligent and sustainable future.

Artificial Intelligence (AI). Enhancing efficiency, sustainability, and the standard of living for residents, AI have the potential to significantly contribute to the growth of SCs. AI-driven solutions can assist SCs in lowering energy use, streamlining traffic, and enhancing public safety. AI systems, for instance, can monitor building energy consumption to spot inefficiencies and reduce waste, or they can analyze traffic patterns to minimise air pollution and congestion. AI-powered chatbots and virtual assistants can also help SC projects by giving citizens real-time information and assistance, including directions or details on local services. AI can also be used to evaluate data from multiple sources, including social media, to comprehend the needs and preferences of individuals and make data-driven decisions that are advantageous to the society.

Digital services. Technologies such as digital twins DT, blockchain BC, virtual reality VR, metaverse, and simulated environments have the potential to completely transform the creation of SCs. Cities can test and evaluate new systems and technologies in simulated environments before implementing them in the real world. Real-time monitoring and analysis are made possible by digital twins DT, which offer a virtual replica of a physical system. The metaverse is a virtual environment that coexists with the real world and presents new opportunities for creativity and teamwork. Robotics and virtual reality VR present new opportunities for SC automation, simulation, and training. Blockchain BC offers a secure and decentralized platform for data administration and exchange, laying the foundation for the creation of innovative SC systems. There are many opportunities for innovation and advancement in quickly evolving field of developing and implementing these technologies in SCs.

Cloud platforms. The development of SCs depends heavily on city platforms, cloud computing, cloud storage, edge computing, hybrid data storage, infrastructure as a service (IaaS), and platform as a service (PaaS). For the control of SC systems, including public safety, electricity, and traffic management, city platforms offer a unified infrastructure. Scalable and adaptable methods for processing and storing massive volumes of data produced by SC systems are offered by cloud computing and storage. By processing data at the network's edge, edge computing EC reducing latency and improving response times. The advantages of cloud and edge computing are combined in hybrid data storage, which offers a scalable and adaptable approach to data processing and storage. The platform and infrastructure for the creation and implementation of SC systems are offered by IaaS and PaaS, respectively. These technologies provide a foundation for the creation of new and creative SCs, which will result in a more smarter and efficient future.

2.1 Cloud-driven IoT-based Big Data

The expanding volume of data is increasing expectations for smart cities. Thus, the IoT-provided massive volumes of data, or big data BD, form the foundation of city infrastructure.

volume, velocity, and different data types define the term BD. A city could gain valuable insights from a large amount of data gathered from many sources based on big data BD technology.

In order to support the development and analysis of smart cities, it is also important to monitor, gather, archive and share open sensor data from IoT devices. A number of researchers have offered diverse formal definitions of a smart city from a variety of viewpoints. Many smart city SC concepts and themes (smart people, smart transportation.) are required as a result of the development of ICT technologies. These should primarily leverage the benefits of data management technologies IoT, BD, and CC) to create a deep connection between every element and layer of a city.

There are certain benefits to cloud-driven IoT-based big data BD. Data about exponential growth throughout time could be gathered and analyzed logically and effectively to support decision-making. Big data BD produced by IoT devices could enable these scenarios because traditional approaches are not cost-effective when handling large volumes of data and are not appropriate for data processing and storage systems.

Due to the availability of enormous computational storage facilities for processing these data within smart cities SC, the use of big data BD in these settings offers both many benefits and constraints. However, this big data BD technology's dependence on cloud computing CC and IoT services is one of its significant advantages. Intelligent networks with complex connections between components and residents' equipment are required for the majority of big data BD deployments in smart cities SC. Therefore, this intelligent connectivity ICon should be able to transfer responses back to the entities and collect data from the resources in an efficient manner. For real-time big data BD applications in smart cities SC, quality of service (QoS) is therefore crucial.

To process big data BD, cloud computing CC represents a good solution. CC is an standard that gives users in the cloud access to a shared platform of computational resources. For example, when it comes to capital savings and expenditures, CC can offer a number of advantages to both individuals and organizations. The relationship between IoT, BD, and CC is showed in Figure 2 based on the references.

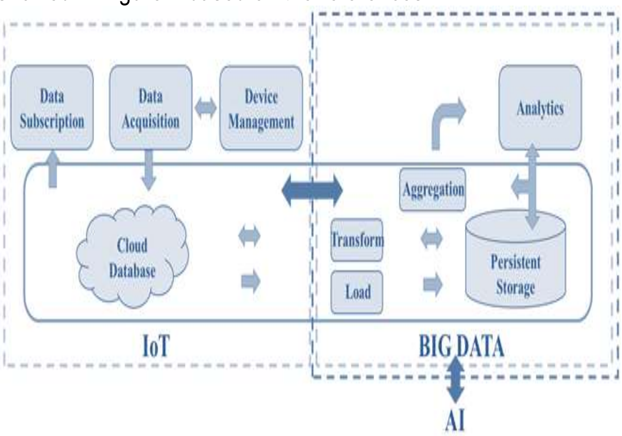

Figure 2 The relationship among IoT, big data BD and cloud computing CC.

CC users benefit from a network-based environment that allows them to share resources and computations from a specific location. NIST defines cloud computing as a framework that facilitates appropriate Internet connectivity and a collective pool of programmable grids, storage systems, software, and servers that could be quickly set free via communication from a provider.

Because data centers in physically accessible locations present a variety of security challenges and risks, CC users are unsure of the exact location of their sensitive data. Furthermore, because threats spread quickly, well-known security techniques like firewalls and host-based antivirus AV software are unable to offer adequate security platforms in virtualized systems. Additionally, CC offers enterprises cost-effective maintenance, limited upfront investment, and instant access to physical resources. CC is also regarded as a powerful enabler that enhances agility and operational activities.

2.2 6G enabling the New Smart City

The sixth-generation (6G) wireless communication is the successor of fifth-generation (5G) communication. Candidate technologies like artificial intelligence (AI), integrated sensing and communication (ISAC), and non-terrestrial networks (NTN) can be used in development smart city SCs as 6G communication systems evolve. Ubiquitous connectivity, artificial intelligence and communication, and integrated sensing and communication are three emerging use cases (Fig.3) [13].

The main themes of the upcoming 6G are s summarized as follows:

• The convergence of sensing, computing, control, localization, and communications: computing, control, localization, and sensing in addition to current wireless communication.

• Smart reflective surfaces and environments: Driven by smart reflective surfaces that serve as walls, roads, doors, and entire buildings, helping to maintain a line of sight and obtain a quality signal with minimal loss.

• Massive availability of small data: Shifting from centralized big data BD to massive distributed small data.

• More resource availability (bits, spectra, and reliability): Higher frequency spectrum (THz), reaching 1 Tb/s.

• Self-sustaining networks: AI to facilitate intelligent wireless networks that are self-sustaining.

• Ubiquitous connectivity that encompasses air, ground, and sea: Integrating the space-air-ground-sea mode to facilitate wireless communications in flying vehicles, XR, brain–computer interface (BCI), and more.

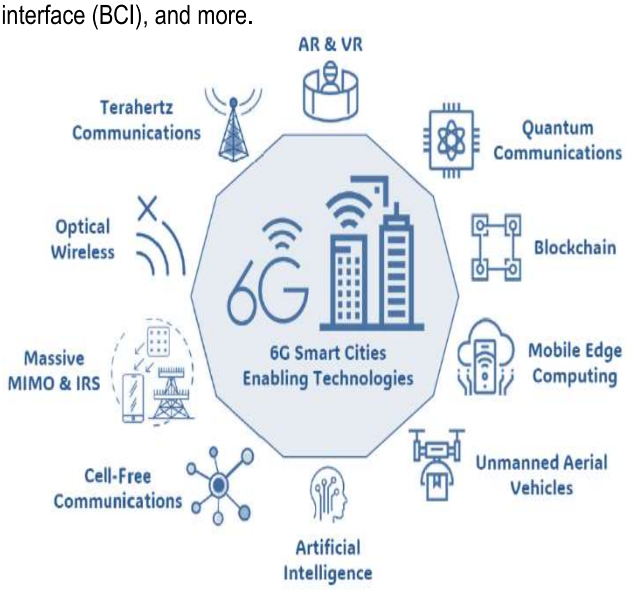

Figure 3 Enabling technologies in 6G for smart cities SC.

From a technical perspective, 6G makes it possible to integrate into a single network with increased throughput and reliability. These features make 6G networks perfect for the widespread implementation of the Internet of Things (IoT) paradigm, particularly given that billions of devices are anticipated to be connected to infrastructure in the near future.

Recently, the draft of the international mobile telecommunications IMT-2030 6G recommendation has been completed and 6 major usage scenarios have been defined [8]. Three of these scenarios, enhanced mobile broadband (eMBB), massive machine-type communication (mMTC), and ultra-reliable and low-latency communication (URLLC) are more complex versions of the IMT-2020 5G usage scenarios. That is, immersive communication, massive communication, and hyper-reliable and low-latency communication (HRLLC).

The foundation of modern wireless communication networks is radio access technologies (RAT), which allow for high-speed data transmission and reliable connectivity for mobile devices. Radio access technologies are developing to offer even faster speeds, lower latency, and increased network capacity with the upcoming new generation of cellular networks.

IoT-based communication is essential to the creation of smart communities. Reliable wireless networks are crucial for the IoT to continue expanding. The usage of RAN or cloud RAN (CRAN) in the developing 5G cellular system, which integrates cloud computing CC technologies into the radio access network, is one way to address this issue. More scalability, flexibility, and performance are offered by CRAN, which makes it possible for 5G to link a large number of IoT devices, all of which are essential for SCs. The concept of network slicing (NS), which enables service providers to design unique virtual networks for various applications and services, is another crucial component of 5G RATs.

Edge computing (EC) involves processing data and performing other computational tasks closer to the source of the data, rather than sending them all to a central data center or cloud. Edge devices, which are located closer the network's edge and have real-time data processing capabilities, can be used to do this. 5G and EC edge computing together can offer a powerful platform for developing previously impossible new services and applications. Using edge devices, for instance, real-time video analytics can be carried out at the network's edge. The processed data is then sent over 5G networks. Numerous uses, including remote surveillance and health monitoring, may be made possible by this. The application of edge computing EC and 5G to driverless cars is another example. Autonomous vehicles can make decisions in real time, enhancing efficiency and safety, by processing sensor data and other information at the network's edge. The presence of a cloud in the IoT system of an SC can result in high energy consumption and network delays. Based on a cloud computing CC, edge computing EC has become a solution to this problem by bringing network, storage, and processing resources closer to the data source. However, a crucial problem in edge computing EC while executing tasks produced by IoT systems is the effective use of energy while maintaining delay constraints. In IoT-based SCs, resource allocation using distributed edge computing EC is studied using a multi-criteria optimization approach. To guarantee effective resource computation for delay-sensitive tasks, an actionable approach-based edge resource allocation method is effective solution for three-layer network architecture for IoT-based SCs. In SCs and the IoT, edge computing EC provides a number of advantages, such as reduced latency, improved security, increased scalability, lower costs, and enhanced reliability.

New SCs might benefit from a variety of cutting-edge technologies, such as remote healthcare, smart grids, and driverless cars, with the aid of 6G networks. Furthermore, cutting-edge technologies like virtual reality, augmented reality, and immersive gaming might be supported by 6G networks, opening up new business and residential options in these places. It might take a few years before 6G networks are generally accessible, though, as their development is still in its infancy. Researchers and business professionals are still investigating the possible advantages and applications of 6G networks in the context of recent advancements in SC. Intelligent transportation and logistics, connected robotics and autonomous systems, worldwide ubiquitous connection, and pervasive intelligence are some examples of use cases that have been identified and presented in the context of SCs.

Better monitoring and control of urban resources based on the development of intelligent infrastructure, such as linked sensors and devices, made possible by 6G networks. This covers data-driven intelligent urban planning, water and energy efficiency, and intelligent waste management. Furthermore, by facilitating greater access to services like such as e-healthcare, online education, and digital governance platforms, 6G-enabled SCs are anticipated to promote inclusivity and enhance people' quality of life.

3 CONCLUSION

As urban environments continue to evolve, the smart sustainable city SC has generated considerable attention. As research and industry studies present, there is a need for a critical reassessment of the entire ICon wireless communication sector for SCs. The development of the SC concept relies heavily on ubiquitous connectivity because the existing communication infrastructure cannot keep pace with the rapid growth and extended operation of SCs.

Smart cities SC are the result of modern ICT development that integrates mobile communications and AI. 5G networks significantly influence the development of SC infrastructure. Along with data analytics and artificial intelligence, the Internet of Things is a crucial ICT technology that facilitates smart networking in urban areas. Smart connectivity solutions have been the focus of several national SC programs. In terms of various degrees of new technologies, practically every city nowadays aims to be SC to some degree. Critical infrastructure integration and monitoring, resource optimization, maintenance activity planning, security monitoring, and maximizing citizen services are all taken into account. An innovative city that uses ICTs primarily to improve the quality of life and efficiency of city operations and services while meeting the needs of present and future generations in terms of the economy, society, environment, and culture is referred to as a smart sustainable city.

The quick advancement of IoT technologies encourages academics to explore new services and application areas. Additionally, by sharing and gathering data inside IoT services, human needs will be taken into account in order to increase awareness of smart city principles. Consequently, sensing, processing, networking, and actuation should all be integrated into the network.

With the development of ICon technologies, we are currently witnessing the ongoing evolution of urban settings. ICTs are helping many cities become smarter these days, increasing the efficiency of infrastructure and traditional services. Both industry and academics are conducting research on sixth generation (6G) technologies in light of the introduction of 5G technologies. One of the best options for enabling SC to support the development of new services and applications is 6G networks.

As technology continues to evolve, the creation of a new generation of wireless technology might be justified for a number of reasons. SCs and 6G are technologies that will transform the way we live and work in the near future. However, combining these technologies leads to a series of challenges that have to be addressed. The challenges for SCs include interoperability, data privacy and security, digital divide, and implementation challenges.

The next generation of SCs is anticipated to be made possible by 6G networks, which offer faster data transfer speeds, lower latency, and increased connectivity. Overall, 6G networks have the potential to transform how cities function by providing faster, more reliable, and more efficient connectivity, supporting a wide range of SC applications.

Actually, 6G requires new infrastructure and technology, which may be difficult to develop and deploy. Like any new technology, 6G may raise security issues that need to be resolved to protect users' privacy and safety. Finally, governments and private industries collaboration are necessary for development and implementation, and regulatory obstacles that need to be overcome. International coordination and collaboration will also be necessary to achieve worldwide conectivity with 6G.

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