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Abstract

Cities around the world are facing enormous strain to sustain and improve the quality of life (QoL) owing to rapid urbanization and rising populations. Management of urban resources in a responsible manner is key to sustainable development in rapidly urbanizing regions. Cities are increasingly making use of modern technologies with a focus on cost reduction, optimal resource utilization and creation of more liveable urban environment. Such cities, called smart cities, have gained traction with policy makers, politicians and urban managers having the attributes of sustainable urbanism, QoL, and smartness. Smart cities provide digital intelligence to existing cities by creating a ubiquitous, integrated and smart environment where IoT applications impart seamless interconnection, interaction, control and insights about the isolated systems within the cities. This paper discusses and reviews the role of IoT for sustainable smart cities by highlighting IoT applications for smart cities. The challenges and opportunities associated with IoT enabled smart cities are also highlighted.

Keyword: Sustainable urbanism, smart cities, IoT, privacy and security, QoL

1. Introduction

Majority of the world population now inhabits urban spaces, with 55 percent of the people living in cites in 2018 and an estimated 70 percent of the world population is set to become urban by 2050 [1]. The most urbanized regions of the world are still in the West with more than 60 percent of their population living in cities. However, other regions of the world particularly Asia is also catching up with the West in this urbanization trend with approximately 50% of its population living in urban spaces. Many of the global cities are experiencing enormous pressure to sustain and improve the quality of life due to rapid urbanization and rising populations. Cities contribute a greater percentage to the Gross Domestic Product (GDP), provide employment, and increase per capita spending, thus driving the country's economy. Cities offer better services, but they also harbour enormous problems like degraded quality of the environment, deficient basic infrastructure and services, increasing exclusion and feminization of poverty. Management of urban resources in a responsible manner is key to sustainable development in rapidly urbanizing regions.

The phrase "smart city" is a new concept that has gained popularity lately. The word was coined by governments, institutions, and citizens, as well as academic and industrial sectors [2]. This new paradigm, which is becoming increasingly popular and appealing, has a lot of definitions. A smart city, for example, may be defined as "a well-defined geographical area in which high technologies, such as Information Communication Technologies (ICT), logistics, energy production, etc. work collaboratively to create benefits for citizens in terms of well-being, inclusion and participation, environmental quality, and intelligent development; it is governed by a well-defined pool of subjects, able to state the rules and policy for the city government and development" [2].

More recently, in combination with an early effort at actual implementation, the smart city idea had been criticized of being overly technology-centred and mostly pushed by the technology enterprises and without any genuine attention to the municipalities and the requirements of people. Consequently, a more sustainable strategy is overwhelmingly necessary.

Internet of Things (IoT) refers to interconnection of things, people as well as objects, to the internet and to other connected devices that enables data collection and sharing. IoT interconnectedness can increase society's ability to build smart and efficient cities. It can analyse and solve problems in architecture, agriculture, safety, surveillance, sanitation, etc., and solve the sustainability concerns. It offers a balance between sustainability issues through processing and information sharing. It also helps communicate the demands and problems of every area with the help of technology sensors. By allowing things to cooperate, strengthening decision-making through improved data collection and improving the surroundings, IoT technology can enhance our effectiveness by reducing resources, applying them and distributing them better. This paper discusses how IoT solutions can be applied to sustainable smart cities. The rest of the paper is organized as follows: Section 2 provides an overview of sustainability, sustainable development for cities and IoT. Section 3 examines the functional capacity of IoT to create smart cities. Section 4 discusses the challenges and opportunities of urban IoT with emphasis on security. Section 5 presents IoT use cases in selected cities of the world. Section 6 concludes the discussion.

2. Sustainable development, Smart Cities and IoT

Sustainability has a long history and is widely accepted, contrary to the idea of smart cities (it was initially presented in 1987). It is based on three major elements or dimensions: social, ecological and economic. A "sustainable city" is an entity which, according to a more modern definition, does not transcend the capacity of the surrounding city's resources and energy resources as well as trash disposal. In practice, the urban resource consumption in a city should not exceed or correspond to the amount given by the natural environment to achieve its objective (e.g., energy, soil or water resources). In addition, the environmental capacities of resorting to residents and other ecosystem members should not surpass the pollution level produced by municipal operations. The notion of sustainability has been challenged to be outdated and inappropriate to the demands of the highly digital world of today, which despite its simplicity and rationalization is characterized by extremely quick changes and growth.

Recognizing cities as the transformative force for sustainable development, the United Nations established a stand-alone and dedicated sustainable development goal on human settlements (SDG 11) that sets out to “make cities and human settlements inclusive, resilient and sustainable” [3]. This goal is reflective of the need for sustainable measures for regeneration of cities in sustainable forms. SDG 11 devotes a significant amount of attention to people and to the common good [4]. There are seven outcome-oriented (refer to figure 1) and three process-oriented targets in SDG 11. The goal of SDG 11 is “to provide safe and affordable housing and public transport and develop well-planned cities with environmentally sustainable buildings and increased public spaces were cultural and national heritage is protected. It also aims to improve resilience to disaster and risk management” [5]. SDG 11 provides an opportunity for rethinking urban planning along the three dimensions of sustainability – social, environmental and economic [6]. Sietchiping et al. [7] argue that SDG 11 can help bring sustainability to the fore of urban planning and development agendas.

Figure 1. Targets of Sustainable Development Goal (SDG) 11.

It is also observed that billions of gadgets and systems are integrated into the infrastructure of a city. These include end-user equipment, municipal lighting systems, road traffic and pedestrian management, monitoring of water and gases, structural monitoring and waste management, and smart medical services, to name a few. In order to improve the safety, efficiency, production and quality of life of its citizens, the city is therefore de facto required to employ ideal computers and communication, integrate, manage and analyse the massive data. Smart city applications aid inhabitants and a basic environment that includes smart economy, smart government, smart individuals, smart mobility, smart environment and smart life [8].

“Though, a formal definition of a smart city exists” [9], from a data management viewpoint, Gharaibeh et al [10] suggested that “a smart city employs a combination of data collection, processing, and disseminating technologies in conjunction with networking and computing technologies and data security and privacy measures encouraging application innovation to promote the overall quality of life for its citizens and covering dimensions that include: utilities, health, transportation, entertainment, and government services”.

The evolution of these concepts led to academics suggesting a new paradigm, dubbed “smart sustainable city,”. More specifically, this paradigm tries to combine a municipality's urban sustainability with smartness, emphasising the importance of considering both factors together in order to achieve the best urban governance. According to a comprehensive definition [11], smart sustainable cities are defined as “innovative cities that use ICT and other means to improve quality of life, the efficiency of urban operations and services, and competitiveness, while ensuring that they meet the needs of present and future generations in terms of economic, social, environmental, and cultural aspects”.

It is crucial to assess the effects of the usage of such intelligent devices on individuals' everyday life. This is based on new opportunities offered by today's wave of technological innovation particularly on the rising application of Internet of Things (IoT) devices and entities. The IoT is a modular approach to interconnect various devices over the internet to enable them to accumulate and exchange data with each other [12]. IoT has been variously defined [13-16] however, Gubbi et al [17] provide a more user centric definition. According to them, “Internet of Things for smart environments is interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications. This is achieved by seamless large-scale sensing, data analytics and information representation using cutting edge ubiquitous sensing and cloud computing" [17].

Smart sustainable cities may enhance many elements of their urban administration through the launch of IoT innovations (as illustrated in figure 2), such as city transport, environmental monitoring, public transit, e-government, public lighting, safety and security. The IoT technology in sustainable smart cities should enable monitoring, control and management of all accessible resources such as water, soil, electricity, people and others.

Figure 2. Essential issues in a smart city. (Source: Adapted from Belli et al. [2], 2020)

The next section examines how IoT functional capacity can help in the creation of smart cities.

3. Functional capacities of IoT to generate smart cities

IoT technologies can produce smart cities in six areas: "smart economy, smart people, smart government, smart mobility, a smart environment and smart living" [18]. Smart cities can connect objects, people and information through computer networks via IoT technologies. In order to deploy IoT technology correctly, sensor-related issues, such as accuracy, bandwidth and cloud computing need to be maintained constantly. Data receivers may influence samples of data collection, numerical variables, and conclusions on infrastructure. The Internet of Things technology comprises of thousands of networked nodes which like a system of functionality, cooperate concurrently, transforming the environmental adaptations into compressed forms of data. IoT technology classifies data via ubiquitous cloud computing through Internet connectivity extension through communication with devices and common items. Many scientists have tried to describe the nature of the IoT. Through different data compilation processes, objects can operate like small computers. Logical patenting, obvious with machine learning, can be predicted and information learned from sensors can be signalled over wireless cloud platforms. IoT technology is important because it can promote smart cities' development and wealth.

As described in section 2, IoT constitutes one of the fundamental technologies for the development of a smart city that involves a steadily growing number of linked devices in various cities. The overview of IoT Analytics' projected number of linked IoT devices in 2015-2025 (also known as smart objects). As is evident from figure 3, the number of IoT devices have been increasing since 2015. This increasing trend is projected to continue till 2025, therefore, reflecting that communication infrastructure needs immediate and urgent attention in smart cities as connectivity anytime and anywhere is what defines a smart city.

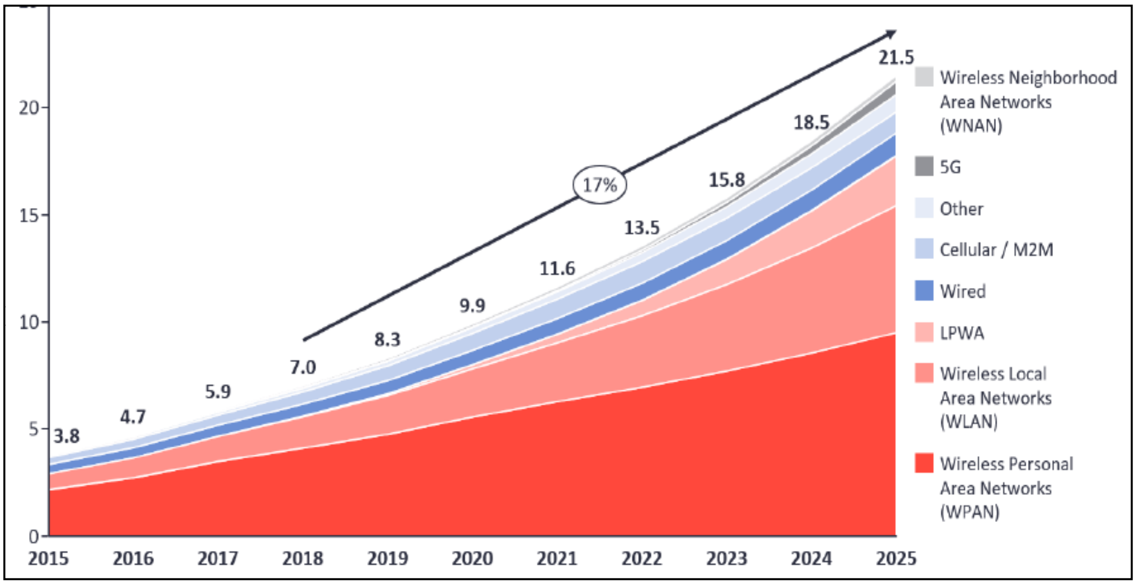

Figure 3. Trend on the global number of connected IoT devices in the period 2015-2025 [19].

Note:- No PCs, laptops, landline telephones, cells or tablets are included in the IoT connectivity. There are active nodes / devices or gateways, not every sensor/actuator, concentrating on end-sensors. Simple one-directional communications technology not considered (e.g., RFID, NFC). Wired includes Ethernet and Fieldbuses (e.g., connected industrial PLCs or I/O modules); Cellular includes 2G, 3G, 4G; LPWAN includes unlicensed and licensed low-power networks; WPAN includes Bluetooth, Zigbee, Z-wave or similar; WLAN includes Wi-fi and related protocols; WNAN includes non-short-range mesh; Other includes satellite and unclassified proprietary networks with any range.

4. Smart Cities: Challenges and opportunities

In this section, we discuss the challenges and opportunities in smart cities.

4.1. Challenges. Although smart cities offer a wide range of benefits to its citizens, there are many hurdles to digital transformation in metropolitan areas. IoT related security is one of the most significant challenges which has been elaborated upon in the latter part of this section. Here's a summary of some of the most urgent difficulties in the development of smart cities:

4.1.1. Infrastructure: Although our everyday life has been greatly affected by the emergence of new technology, the infrastructure in most cities has remained untouched since the nineteenth century in general. Smart city projects need a strong foundation to thrive on, understandably. In particular, IoT sensors capturing different data from air pollution to traffic congestion levels require modern infrastructure supported by novel technology in order to completely deliver their worth. In most developed cities, various infrastructural difficulties such as water and steam pipes, Internet broadband, energy etc. still exist.

Thus, the successful infrastructural modifications depend on the allocation of intelligent resources, generous finance and complete government assistance.

4.1.2. Privacy Concerns. Most people want to profit from smart city projects and benefit from greater safety, lower crime rates and better living standards. The price to pay, though, many feel is invasive and maybe menacing. Monitoring cameras can lower the rate of speeding vehicles and other offences in the city, but these cameras also create the feeling "big brother watches", thus, generating fear. The volume of personal data collected by IoT smart sensors is a matter of grave concern for citizens. Full transparency of the usage of data as well as education efforts to inform citizens of the way in which smart cities function, ought to at least partly assuage these worries.

4.1.3. Smart cities security issues. In smart cities, security concerns arise because many individuals are suspicious about smart city programmes. IoT devices are basically safety gaps. The increasing quantity of IoT sensors and the expanding interdependence of interdependent urban silos poses legitimate issues. If the safety standards remain unchanged, cyber criminals might shut down a whole city. Fortunately, technology companies are inventing security solutions based on large-scale analysis, blockchain and encryption technology that are meant to manage ever more advanced cyber threats. In order to eliminate risks, smart city developers invest in these latest generation security technologies.

4.1.4. Social inclusion. Examples of adequately implemented efforts could be beneficial in assuring inclusiveness while developing smart cities. If inclusiveness is not achieved, the best intentions could possibly be negated. For example, because many people do not know how to utilise the technology, a town might not undertake a health project for the elderly people. In order to promote social inclusion and to communicate with all the stakeholders in the city, smart city initiatives should be carried out. Besides the above-mentioned challenges, other challenges related to citizens, mobility, environment, and governance was forwarded by Belli et al [2]. These can be specifically sub-categorized into various ground level challenges. The details of this classification are given in table.1.

Table 1. Classification of Smart city challenges.

Citizens	Mobility	Environment	Governance
• Unemployment • Social cohesion • Poverty and inequality • Aging population • Data safety and privacy • Urban violence and insecurity • Shortage in access to technology • Health and emergency management • Deficit of social services	• Sustainable mobility • Inclusive mobility • Multimodal transport system • Interoperability • Traffic congestion • Alternative mobility • Lack of public transport • Weak ICT infrastructure • Pollution	• Energy saving • Holistic approach to environmental and energy issues • Climate change effects • Rapid population growth • Energy resources scarcity • Water scarcity • Pollution	• Flexible governance • Territorial cohesion • Interoperability • Combination of formal and informal government • Gap between citizens and government • Unbalanced urban development • Deficit of social services • Unemployment • Sustainable economy • Weak ICT infrastructure • Shortage in access to technology

Source: Adapted from Belli et al.[2] (2020)

4.2. Opportunities

Though a number of challenges exist for smart cities, they also offer numerous opportunities, some of which are discussed below:

4.2.1. IoT management. IoT needs a safe, efficient architecture to improve the collection of urban data. Omnipresent and cooperative, smart urban sensing can offer a smart environment. Others are unavoidably not controlled, such as latencies and packet loss. One idea is to "employ the MANET nodes as mobile relays to swiftly gather urgent data from wireless sensor networks without sacrificing battery life" according to the coordination protocol of Mobile Ad hoc Networks (MANET)[20]. Their cluster generation process, according to simulation results, is trustworthy and reliably transmits more than 98 percent of packets in street and square circumstances [20]. Other issues, such as the intersection of IoT and intelligent transportation systems, require greater investigation.

4.2.2. Data management. In a smart city, data is crucial. Smart cities will generate vast amounts of data that will be difficult to understand, manage, and analyse. On the other hand, mobile phone data can help achieve a variety of smart city objectives. Data from mobile phones can be used to create a variety of urban applications. Mobile data, for example, might be used to predict the volume of traffic and other mobility demands. It is possible to perform a transportation analysis. Data from mobile phone sources and data from taxis' Global Positioning Systems can help manage transportation resources in the future, such as public taxi demand. A smart city requires a lot of data storage, which can be done with a metasurface or a bunch of nanoantennes. This technology has the potential to have an impact on a variety of fields (such as encryption, imaging, data storage, and communication). The response of a given smart city to unknown facts is critical, as is the topic of how to gauge a smart city's strength.

4.2.3. Smart city assessment framework. The city's quality of life, including health, safety, and wellness, must be monitored. Using an evaluation framework, several characteristics such as smart city initiatives and stakeholders' interests must be taken into account [20]. Its goal is to compare and analyse the characteristics of various smart cities in order to identify new issues, measure advantages, and assess performance.

4.2.4. Vehicular ad hoc network (VANET) security. In smart cities, a major need for VANETs is efficient security support. One aspect is how they may be secured by developing solutions which minimise the possibility of network assaults and can also lessen the impact of a successful attack. In the field of authentication and driver analysis, certain security issues exist. A smart city requires “lightweight, scalable authentication frames to protect drivers from external or internal attackers” [20].

4.3. IoT Smart cities security

Although the cities seek to be smart through the adoption of various solutions, smart city applications emphasize a few privacy and safety concerns, as city operators are expected to defend the information generated or gathered from unauthorized access [21].

Information, communication and physical worlds should satisfy core security and data security standards, including confidentiality, integrity, non-repudiation and accessibility, access control and privacy [22]. In addition to these fundamental needs, the protection of an intelligent town nevertheless faces a series of specific problems. On the one hand, an intelligent city collects granular and confidential information that is sensitive to people's lives and environment; on the other it analyses and manipulates this information and influences people's lives. Some of the major security issues related to IoT in smart cities include:

4.3.1. Privacy Leakage in Data Sensing. A smart city is subject to private leaks and information provided by external adversaries since data is gathered, transferred and processed in private cities. In a smart city, disclosed privacy can contain the identity and location of the user in the transport industry, health status in healthcare, intelligent surveillance-driven life style, smart power, house and community etc. It would be huge supervision to divulge this information that is important to privacy in both the physical and communication realms to unauthorized entities.

In order to protect user privacy during data collection, several security and privacy measures, including encryption, anonymity and access reserve can be applied. Martínez-Ballesté et. al. [22] propose to use smart city applications with a range of privacy principles and criteria. They propose a five-dimensional model of citizens' privacy in smart cities including identity privacy, query privacy, location privacy, footprint privacy and owner privacy to tackle generic difficulties related to data breach. However, certain private information can still be exposed inadvertently to unreliable entities.

Smart surveillance, for example, may record indices, styles or even privacy of local inhabitants, while originally meant to monitor crime in actual and virtual circles. In an intelligent home, a camera also detects burglary or odd occurrences using a monitoring camera. Private information about your home area may be obtained by infiltrating attackers in a smart house which harms the privacy of the residence. Majority of current security and privacy protection against external assailants and attackers have been addressed. However, prospective attackers inside the community, including agencies, staff, and security guards, who may access monitoring data can either steal information from consumers or leave a loophole for external attackers. In addition, the data in a smart city are of high granular size and of various type that vary with privacy needs. The development of customizable methods for protecting privacy in a smart city is a challenge to reconcile the compromise between privacy and efficiency [23].

4.3.2. Privacy and Availability in Data Storage and Processing. Because a smart city has the capacity of cloud servers to store and analyse data across information, cloud servers confront security threats. If smart city data are in plain texts, they are disclosed immediately to the cloud server during storage and processing. An option would be to encrypt the intelligent city data and transfer ciphertexts for storage and processing to the cloud server. Whilst the untrustworthy cloud server prohibits direct access to information collections, it is not possible for the cloud server to handle encrypted data and carry out effective analysis for intelligent urbs. The newest advance in completely homomorphic encryption illuminates processing by encrypted data, for instance, summing and comparing. Another difficulty in terms of performance is the processing overhead, especially when mass data is used in a smart city.

The data sharing and access management is another difficult problem to secure a smart city. For instance, data from the road can be gathered in the form of a crowdsourcing via placed cameras or cell phones and GPS. It is difficult to set access policy during global road planning and to facilitate the private sharing of data across employees. Smart city data storage and exchange therefore require a lot of research.

4.3.3. Trustworthy and Dependable Control. The intelligent city with double-way control depends on the control system and on the drive systems for conducting the operations of the control centre. The systems to regulate and feedback, especially in public and industrial infrastructure, in the physical world are becoming more appealing targets for terrorists, attackers, and criminals. Spoofing attacks, denial of service assaults, and malicious injections of data would disrupt the city of smart business, which would be impaired in management, control and operation [24].

Most malicious attempts and misbehaviours are identified via inspection and auditing by third parties. In Akhunzada's [25] work, the capabilities of data integrity and digital signatures are used for data integrity, access control, and more in software-defined networks. Confidential computing is a state-of-the-art approach to resist modifications of operating system and applications. But these systems need high delay and high false rates in order to identify "intelligent" assaults in an intelligent city. As control reliability is regarded the highest priority in a smart city, it becomes harder to identify hostile assaults and misbehaviours, necessitating a coordinated effort across many parties involved.

The next section examines the application of IoT in smart cities.

5. IoT use cases for smart cities

Smart cities can be made sustainable by making a better use of public resources, offering better quality services to the citizens while reducing the operational costs of public administration [26]. IoT applications can help achieve this goal by creating cost-effective municipal services, enhancing public transformations, reducing traffic congestion, keeping citizens safe and healthier [27]. As IoT uses the internet for merging different things, it is important that all existing things get linked to the internet for remote usage and monitoring. Some of the major applications of IoT for a smart city is illustrated in figure 4.

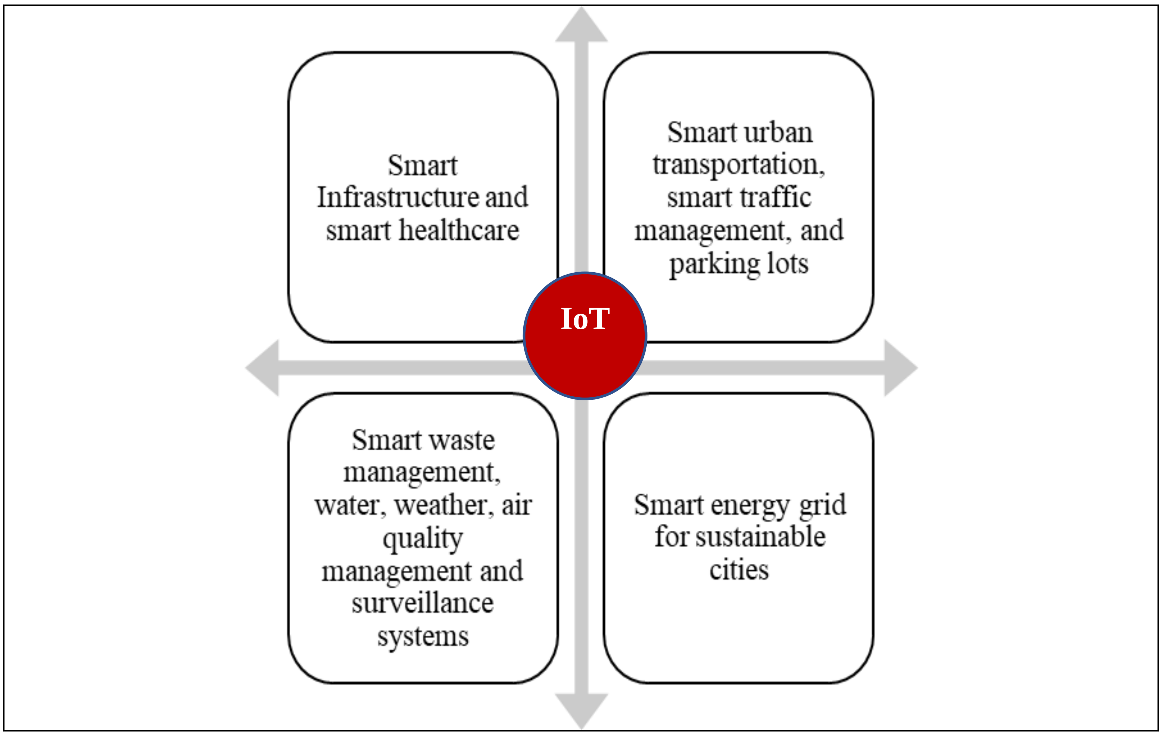

Figure 4: The main applications of IoT

5.1. Major applications of IoT for a smart city

5.1.1. Smart Infrastructure and smart healthcare. Smart infrastructure includes smart homes, offices, schools, data centres, factories, ware houses, etc. Application of IoT technologies for smart buildings can help manage security, surveillance, automated operations, energy management, and so forth distantly. Smart homes, smart offices, smart warehouses, and other smart buildings perform their tasks efficiently and accurately [28]. For example, a smart home uplifts the quality of life of its inhabitants by efficiently and effectively controlling home appliances, energy consumption, surveillance, lighting and temperature control, etc. [29-32]. Sensors used in smart appliances and systems help in checking the environment state and then taking suitable action like dimming lights or switching off air conditioner. Such smart systems also help in demand prediction. Similarly, the productivity of supply chain management can be enhanced using smart warehouses [33]. The most significant benefit of smart homes and buildings is convenience to the users as they are freed up top perform other responsibilities.

Sustainable smart cities should have smart healthcare systems in place. IoT applications can be used in medical care by improving medical information systems. "Innovative data capture offers continuous and ubiquitous medical device access from any connected device over the internet" in IoT-based healthcare [34]. Tracking people and things, such as patients, medical personnel, and ambulances, identification of individuals, and automatic data collecting and sensing are just a few of the benefits of IoT-based healthcare in smart cities [27]. Citizens can avail online appointment, online doctor's consultation, monitor patient vitals using wearable sensors, and other medical services. Patient tracking in clinics and hospitals helps in providing faster and better services, object tracking (ambulance, blood, medicines, etc.) help in checking their availability. Wearable sensor devices by patients provide real-time information on their health indicators and thus, help in getting timely medical advice and support. Various mobile health (m-health) platforms offer health services for remote monitoring of patients and communication between professionals, relatives and patients. m-health platforms are user-oriented, can be personalized and allow easy access to a number of services and knowledge [35].

5.1.2. Smart urban transportation, smart traffic management, and parking lots. Urban transportation system can benefit significantly by IoT applications. Smart urban transportation system includes among others automatic number plate recognition, vehicle counts on the roads, traffic signal automation, smart lighting and smart parking. Application of IoT in managing vehicular traffic information can help in real-time traffic management, thereby, benefitting the citizens, urban governments as well as the urban environment. A combination of sensing capabilities, GPS installed modern vehicles, air quality and acoustic sensors along a given road is of great help in traffic monitoring and in making the cities sustainable [36].

Lack of proper parking in cities is a major concern for the citizens. Smart parking lot applications can monitor the number of vehicles as well as their arrival and departures in different parking lots of the city. Usage of road sensors and intelligent displays help the drivers find the best path for parking in the city. Smart parking lots offer a range of benefits to the users, vendors/contractors of the parking lots, the government and the general public. Finding parking lot faster means less vehicular pollution, lesser traffic congestion, and happier citizens [27, 37].

5.1.3. Smart energy grid for sustainable cities. Smart grid refers to the integration of traditional electrical power grid with latest telecommunication and information. IoT is one of the most recent enablers for smart grid technologies [38]. In a variety of circumstances, the Internet of Things may be used for cost-effective power generation, management, transmission, and consumption. Intelligent and autonomous controllers, advanced software for data management, and two-way communications between power utilities and customers are all part of an automated and advanced energy distribution network created by an IoT application for smart grid [27].

5.1.4. Smart waste management, water, weather, air quality management and surveillance systems. Quality of life in a smart city is determined not only by smart physical entities like infrastructure and other facilities but also by its environment. A clean and healthy environment is the one of the pillars of a sustainable smart city. Most of the cities around the world face the challenge of managing their waste which is generated daily and mostly end up in landfills at the outskirts. Urban waste management includes processes such as collection of waste, disposal, recycle and recovery, managing and monitoring of water materials [39]. Use of IoT in waste management may result not only in significant savings but ecological advantages as well. IoT can "connect the end devices", such as intelligent garbage containers, to a control centre, where data is processed and the best way to run the collection truck fleet is determined using optimization software [26].

Similarly, water and weather systems can utilize diverse sensors in an IoT-based environment for data management related to water distribution, temperature, rain, solar irradiation, and wind speed. The data can be analysed to forecast rains and other weather conditions including floods, detect leakages in water distribution systems, enable the urban governments to develop innovative methods to plan and manage scare resources like water through IoT. Air quality can also be monitored using urban IoT. This can be done by deploying pollution and air quality sensors across the city and making the data available to the citizens on a real-time basis.

One of the most critical factors in any smart city ecosystem is the issue of security and privacy. It must be ensured that every entity in a smart city is secured at all times and therefore, constant monitoring and observation is needed. Conventional security techniques like CCTV systems do not have the capability for intelligent data processing. IoT applications can create smart surveillance systems that can raise alarm in case of any security lapse and help in crime reduction, improvement in city management, crime detection and resolution.

5.2. Urban IoT applications around the world

IoT applications for sustainable urban management is gaining traction with policy makers, businesses as well as individuals. Widespread diffusion of IoT backed by popular demand and technology advances could lead to an invaluable contribution to the economy. Some examples of urban IoT applications in the world are given below:

5.2.1. London (United Kingdom). London is well recognised for its excellent passenger management and transit networks. Congestion management based on number plate identification was effective in minimising traffic bottlenecks during peak hours. Wi-Fi connectivity on the Tube, automated road management, and cycle-rental programmes are among the numerous IoT-based smart applications[28]. London applies IoT for smart waste management under the London Plan. The data is connected to a centralized server for real time monitoring and management.

5.2.2. Santander (Spain). The largest testbed for IoT deployment is the SmartSantander project in Santander city in Spain where 12,500 sensors have been deployed across the city. These sensors use an IoT network to monitor the environment, the number of pedestrians, available parking spots, and the remaining volume of garbage bins, among other things, in order to establish smart transportation and smart communities [28].

5.2.3. Nice (France). The city of Nice in France is using the IoT to digitize existing services and create new ones. The French city has designed an eco-city zone for a sustainable smart city, collecting varied data and sharing the processed data with the citizens with an aim to improve quality of life in Nice[2]. Nice employs IoT-services for urban mobility, energy and environment monitoring and waste management.

5.2.4. San Francisco (United States). San Francisco utilizes IoT technology to improve operational performance of buildings, extend transportation systems, centralize waste management procedures, and reduce energy consumption. Thus, San Francisco has smart energy, smart community, smart transportation and smart community serving its citizens.

5.2.5. Barcelona (Spain). Barcelona has achieved a wide range of benefits of a smart city by utilizing IoT for urban systems such as LED-based street lighting, waste disposal with the use of smart bins, smart public transportation including cycles and bus transit systems, low-cost and easy-to-use sensors to detect noise pollution, open access data, and smart water management systems.

6. Conclusion and significance

In this paper, we have investigated the sustainable smart cities and Internet of Things (IoT) and discussed how IoT technologies interconnectedness can increase the society's ability to build intelligent and efficient cities. Next, we defined the goals for urban development and sustainable development such that the smart cities planning can be achieved with proper regulations and infrastructure. We further focused on the smart city challenges and opportunities, where the challenges in the development of smart city have been categorized. We paid particular attention to the issue of safety and privacy in upcoming smart city applications. We have examined and emphasized factors such as data sensing privacy leakage, privacy and data storage and processing accessibility, reliable control and reliable control. In addition, we presented case applications for smart cities focusing on smart infrastructure, intelligent parking, intelligent trash management and air quality control.

This paper is particularly significant for practitioners and public policy experts including government. It sheds light on how IoT can be employed for an inclusive sustainable city. The concerned government authorities can use the insights of this study in effective implementation of smart cities to make our cities sustainable. We expect this paper will provide further insight into the safety and privacy of intelligent cities, which will show a further pioneering research effort along this new path.

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