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Amalgamation of Advanced Technologies for Sustainable Development of Smart City Environment: A Review

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ABSTRACT The concept of smart city evolved with the integration of information and communication technology (ICT) in various sub-systems and processes in urban environment. The development of the smart cities is the best possible solution to major urban issues. It contributes towards economic and social development of the residents. It aims to provide the cordial environment in the domains of healthcare, education, transportation, power generation and dissipation, security, living, industry, etc., to the inhabitants to make their lives comfortable. Sustainability of these services is another major objective in a smart city framework. Along with the true realization of the idea of a smart city, advanced computational and communication technologies are contributing hugely towards its sustainable development. Communication technologies act as backbone to ensure connectivity at the various levels in a smart city framework. Novel smart city solutions for different application domains are designed and deployed by the industry using advanced computational technologies like IoT, Artificial Intelligence, Blockchain, Big Data and Cloud Computing. In this work, authors discuss the concept of smart city, its architecture and sustainability. Different operational domains in a smart city ecosystem are elaborated. The cyber physical aspect of the smart cities is discussed in brief. The role of various computational and communication technologies in the sustainable development of smart cities is presented. Limiting factors in the deployment of various advanced technologies in different smart city domains are highlighted. Security issues associated with the technological sustainable development of different smart city services along with existing solutions are discussed. The article is concluded by highlighting the future research directions.

INDEX TERMS Artificial intelligence, big data, blockchain, cloud computing, Internet of Things, smart cities, sustainability, wireless sensor networks.

I. INTRODUCTION

A. CONCEPT

In the recent years, as the world's population continues to grow, the main focus is on the development of the cities to meet the growing social, environmental, and economic needs

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of the residents, as well as improving their Quality of Life (QoL). New developments called "smart cities" are on the rise as a result. Internet of Things (IoT), Information and Communication Technology (ICT), and other technologies are combined to address urban issues. The most important goal is to ensure that available resources and technologies are utilized to their maximum potential to construct intelligent cities.

The central role of a city in sustainable strategic development is increasing; so, more and more cities are operationalizing and applying it. This emerging paradigm has pushed cities to a new position of power [1]. According to the 2030 agenda goals proposed under the United Nations' Sustainable Development, there is a need to develop more sustainable and resilient cities [2], [3]. The UN's 2030 Agenda considers ICT as a way for promoting socio-economic development and environmental protection, as well as increasing resource efficiency, and improving human progress and knowledge in the society [4], [5]. The unprecedented effects are currently ongoing around the world, with urbanization and the introduction of new technologies among the most significant changes. This will result in a major and total transformation in urban planning. It is widely expected that the urban world will become mostly technological and automated by the early 2030s, and it will raise the demand for advanced technologies in order to deal with urbanization challenges [6]. With the adoption of various advanced technologies, it has become important to start to proactively understand and manage the potential effects of urbanization to address intractable problems in functioning, management, planning, and development in particular in terms of sustainability [7]–[9]. Most certainly, urbanization is an important and unparalleled challenge due to depletion of resources, environmental degradation, intensive energy consumption, contamination of air and water, disposal of toxic waste, and poor decision-making procedures [6]. These factors affect QoL, well-being of residents, urban operations, and activities [10]. In brief, unsustainable development caused by these limitations in contemporary and future cities can worsen urbanization. The city's sustainability is at risk because of rapid urban growth [11].

As a result, more and more complex technologies have risen to the forefront, and are imperative in mitigating the consequences of urbanization as well as confronting sustainability issues. This advancement arises from the growing use of ICT and its integration in many urban systems and domains, together with the enormous adoption of its applications. To begin with, current and future cities will need new and advanced sophisticated technologies and mechanisms to address their challenges and issues for sustainable development. It will assure optimal management, planning and operation of the cities, including monitoring, understanding and analysis to enhance and protect their commitment to sustainability [6], [12]–[15].

People have started to understand the role of contemporary technologies to solve numerous sustainability issues due to the potential of inspiring and accelerating sustainable development processes [16], [17]. Nowadays, the employment of cutting-edge technology to achieve sustainable development goals is commonly referred to in urban development plans. This approach encourages the development of new sophisticated technologies that can separate the city's health and QoL from energy consumption and materials and the resultant ecological hazards. Recent research has focused on

integrating sustainability into the idea and technique of smart cities with respect to emerging technologies in various kinds of computing [11], [18], [19]. To make cities more smart, more and more modern technologies must be deployed, ranging from featuring multiple data processing, cloud-fog computing, and wireless networking to infrastructure, design, natural ecosystems, community services, and even public bodies. As a result, many of the options and prospects in this respect have to do with smart cities, a type of city which has the potential to be visionaries of the future and to embed a proliferation of sophisticated technology into the city itself [13], [20], [21].

The early ideas for smart cities were mostly focused on applying digital and advanced technological innovation to city services in order to increase their efficiency and provide new economic opportunities in cities [22]. But, greater emphasis needs to be devoted to the distributional consequences of smart cities, i.e., making an assessment of the advantages and costs of smart cities on people, the planet, and places.

The cities of the future will be much smarter, and smart city evaluation is going to be an essential component, as it has a major impact on directing and supporting smart development of cities. The current smart city assessments and the creation of new applications are currently being studied in most nations. The main focus is on evaluating one particular feature, employing indicators with regional characteristics, and having limited extensibility. These factors have led to inaccurate assessment conclusions [23].

There has been a recent rise in the public's interest in smart homes and cities because of the following reasons [24]:

- Major economic development has taken place in populous countries like China, India, and Brazil (40% of the world population is attributable to these three nations).
- More extensive usage by individuals and organizations worldwide of communication and information technology.
- Considerable attention is being paid to protecting the environment and lowering CO₂ emissions.
- The group of senior adults (65 and older) needing intelligent houses/apartments and green infrastructure to make their lives healthy and comfortable in countries like Japan, Europe, and China and other places at affordable prices is notable.
- Fast population growth in major cities.

B. DEFINITION

While the idea of a smart city is still under rapid development and unclear as to what form it will ultimately take. In practice, however, most smart cities are focused on projects that apply digital innovation to service delivery, allowing the cities to be more efficient and to gain a competitive advantage [22]. Designing a city around the needs of its people is considered critical to making it more intelligent. The failure to handle urban concerns in a holistic manner via

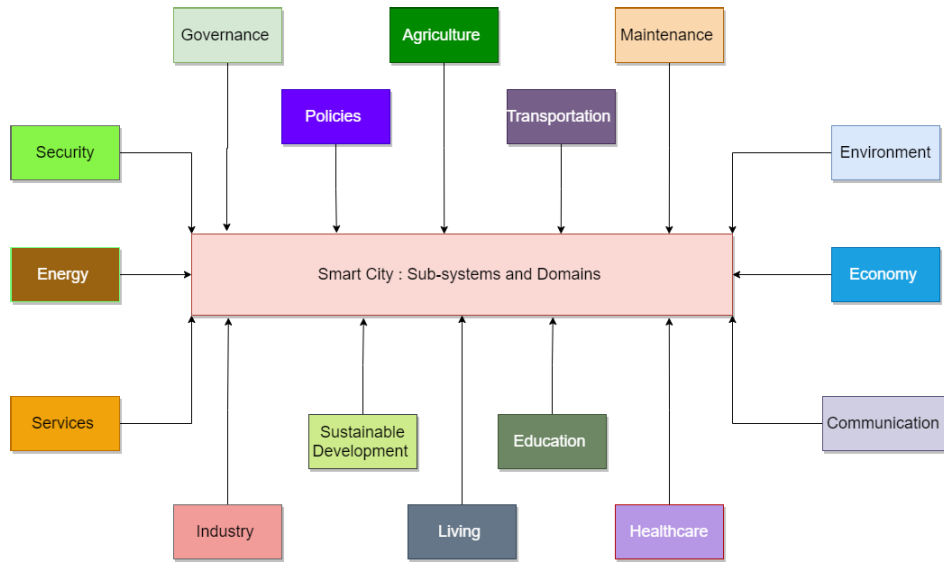


FIGURE 1. Smart city ecosystem: Sub-systems and domains [24], [29], [30].

technology transformation in administration, planning, and infrastructural investment is a big challenge.

Smart cities consist of several interconnected components which constantly exchange data and facilitate better living for the population of a nation [24]. A blend of next generation ICT technologies, including the IoT, Wireless Sensor Networks (WSNs), cloud-based computation, big data analytics, mobile internet, as well as other data-intensive disciplines, is being used for building an intelligent city [25]. The safety of WSN applications is among the main challenges in smart cities. Active continuing or unknown attacks in resource-controlled WSNs are usually clear of discrete defense components [26]. The characteristics that constitute a city as ‘smart’ include [24]:

- Using real-time data sensing to deliver city services that are more intimate
- To aggregate and parse all of the data
- Allowing a seamless method of having access to data that integrates many interconnected domains

C. SMART AND SMARTER CITIES: RESEARCH STRANDS FROM A GENERAL PERSPECTIVE

The research in the domain of smart cities can be approached from a trans-disciplinary and multidisciplinary point of view. In smart city applications, solutions to the various challenges involve many components covering various aspects like impacts, rewards, opportunities, prospects, trends, global shifts, and practices. The subject of smart and intelligent cities incorporates a wide range of studies, including fundamental, analytical, applied theoretical, practical, discursive, futuristic, visionary, socio-tech, and more. There are many different perspectives and techniques reflected in the wide variety of study in this field [6], [15].

The rapid development of IoT has made the smart city an emerging paradigm, consisting of omnipresent sensors,

diverse networking architecture, and smart information and management systems [27]. A smart metropolis can examine the physical cosmos in actual environments and provide smart transportation, health, environmental, entertainment, and energy services to both local people and travelers. However, there are privacy and security concerns as smart city apps collect not only a wide variety of information that is sensitive to privacy, but also regulate municipal facilities, and influence the lives of individuals.

The development of smart cities geared up with a wide range of new focus and goals, and holistic and integrated approaches that are demonstrated by a huge number of researchers, scholars, academics, designers, and professionals in their work. In the broader sense, the smart and intelligent urban field combines a diverse academic background that involves many research areas. In the last decade, the body of literature has grown significantly in the field of smart cities, bringing new social issues and considerations to the fore and offering new potential uses of technology. But it has been observed that the impact and relevance of technology innovations in urban environments is underappreciated yet [28]. Some of the main subsystems in the ecosystem of the smart cities are shown Figure 1.

D. SMART CITY FRAMEWORK

A smart city provides a source of sustainable economic development for investment in human and social capital including the traditional along-with new communications infrastructure [31]. The architecture of buildings benefits from the telecommunications infrastructure in the absence of wired electricity network. Wireless protocols like WiFi, bluetooth, as well as Radio-Frequency Identification (RFID) are utilized in places of limited access or without cable installations. A proper selection of exterior and internal architectures adapted to the geometries and to the distances

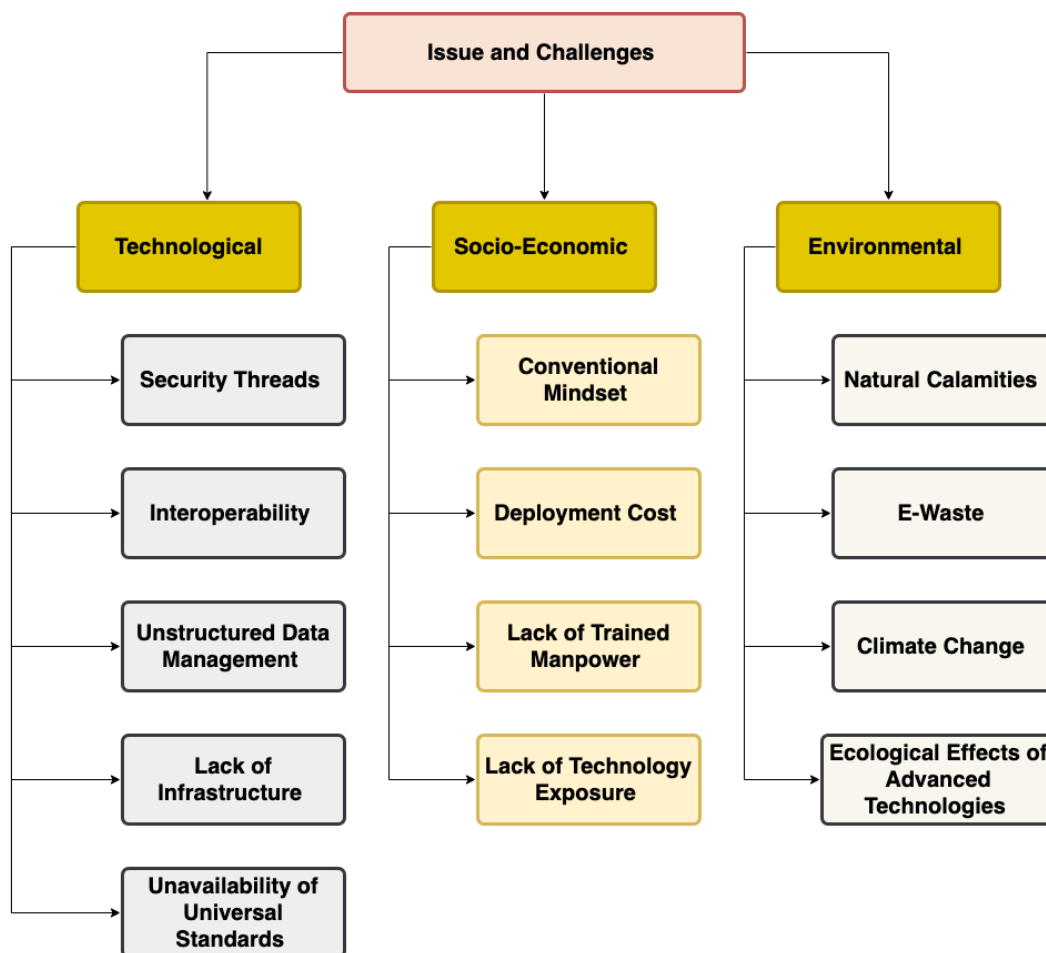


FIGURE 2. Issues and challenges in the development of smart cities [24], [26], [27].

covered will permit correct communication with all the city’s sensors and equipment, and the correct and unerring data for analyzing and optimizing resources without any errors or latency [32]. The development of a successful smart city ecosystem, as outlined in Figure 2, is linked to several inherent and external challenges.

The concept of simple and efficient living doesn’t represent only a new technological innovation, but the incorporation of technology to assist in the automated decision-making. Several new technologies including deep neural networks, intelligent systems, IoT, computer vision, predictive analytics, and big data analysis, have made this goal achievable [33], and made urban living smart and sustainable. The implementation of current technical solutions has allowed smart cities to be a reality. An interconnected network of devices and entities of a smart city are made possible via the use of numerous existing and emerging technologies. Based on the implantation of the sensing devices, smart city architectures can be broadly classified in two types:

1) EXTERNAL ARCHITECTURE

To know what is happening in the city, a number of sensors must be placed that allow specific metrics and variables

to be achieved in the decision-making processes across the environment. On the other hand, various sensors offer the city with different structures, most prevalent being the star architecture or network mesh.

2) INTERNAL ARCHITECTURE

The way sensors are placed inside a building depends greatly on the building’s geometric shape, whether or not the building is deemed an asset of heritage, using the building - sensing an office building will not be identical to a sports hall or even a train station, property ownership, public or private, and new building or old building criteria. The architecture and sensor configuration of new buildings is another milestone in the planning process. However, in an existing building, the above criteria need to be evaluated, and sensors are deployed for the effective functioning of the IoT- systems. Various categories of sensors installed in smart buildings includes proximity sensors, humidity sensors, motion sensors, smoke sensors, temperature sensors, image sensors, gas sensors, accelerometer sensors, IR sensors, and pressure sensors, etc. Decision to choose right sensor configuration for a variety of IoT-systems is very crucial, and made on the basis of type of application. Sensors are

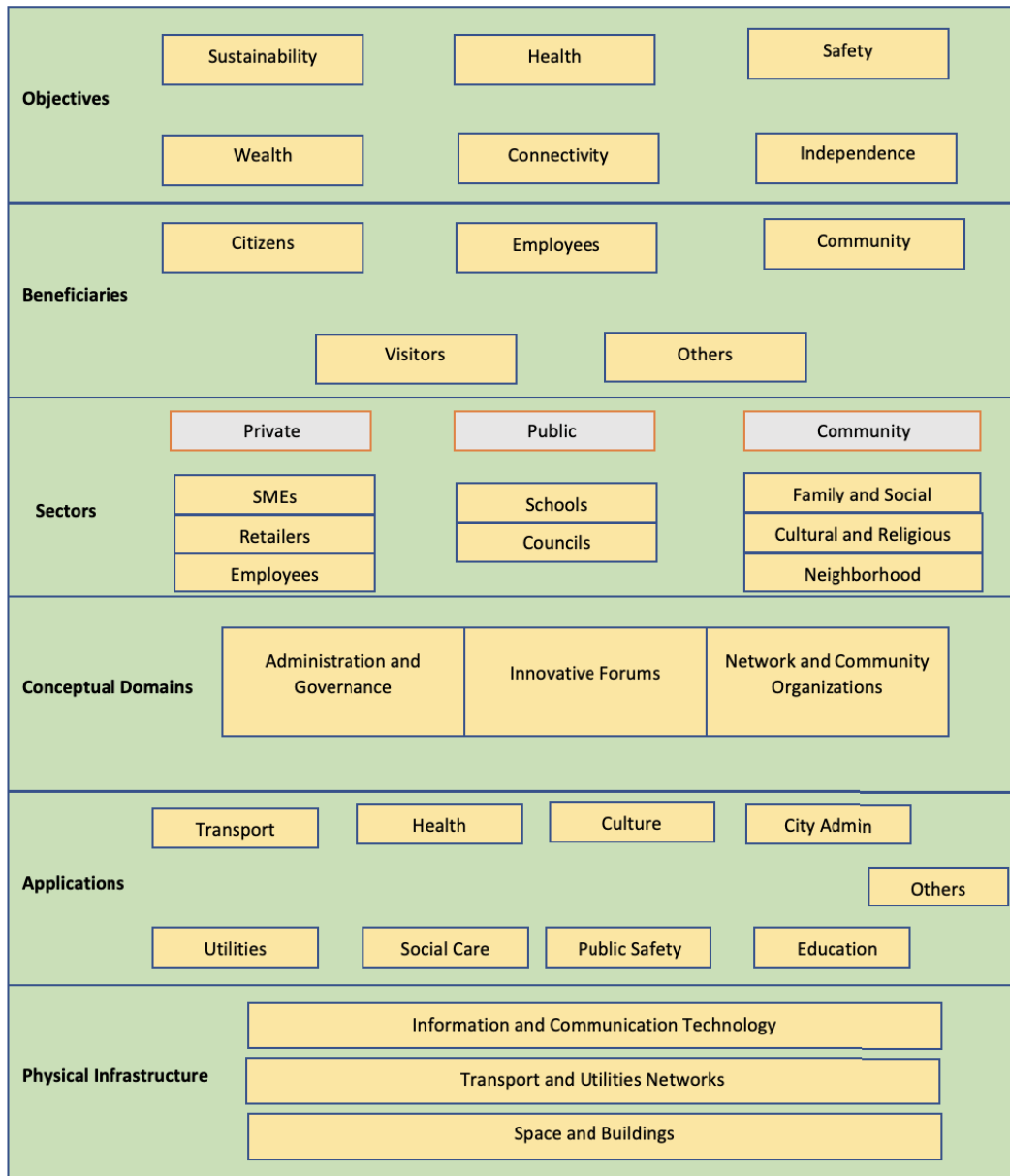


FIGURE 3. Smart city framework: Key components [34].

classified on the basis of transmission range. A sensor configuration may be categorized as short range or long range. Battery life/energy consumption is another important criterion need to be considered in sensor installation. Optimized sensor configuration helps to achieve enhanced data transmission utilizing limited resources in intelligent buildings in a smart city ecosystem. The word “optimized” is also interpreted differently in different types of the buildings. In a constrained environment, like a factory (with reachability issues), battery life is considered as an important parameter before installation. On the other side, in a smart home where complete reachability is the main requirement, high energy consuming sensor configurations are installed to ensure efficient and accurate transmission

without any network failure [34]. Furthermore, the concept of optimized resource utilization can be considered beyond network and communication resources. Sensors installed at various locations can collect status information of other vital elements in the environment, and can facilitate decision making for their efficient utilization [35], [36]. For example, in smart buildings, different resources like water and room heaters, air conditioners, fans, lights, etc., can be monitored to provide comfortable living of the residents and administer energy consumption.

E. SUSTAINABILITY AS A GOAL

Nowadays, the researchers’ main focus of the investigation is on whether or not smart living has a connection to sustainable

cities [37]. While it is of critical importance to define the intent for which intelligent solutions need to be used, and also to assess whether or to what extent such solutions help to maintain sustainability. The critics have claimed that traditional measures of intelligent and smarter cities do not contain minimum sustainability requirements [38]. It seems that the concept of intelligent cities stresses how the substance behind intelligent solutions is linked to sustainable development, including environmental sustainability; this is actually a simplification of how smarter cities help the world. Research is starting to investigate technological propositions that are central to whether cities are better suited to accomplishing environmental sustainability. However, this new wave of inquiry often did not take into account sufficiently well-established strategies, such as concentration, diversity, compactness, and mixed land utilization as well as passive soil design, sustainable transport, environmental restoration, renewable energy sources, and design coding as well as ecological control and management, environmental policy and renewable energy [39], [40]. The assumption behind these methods is that the integrated and constitutive technologies can significantly advance their outcomes if they are implemented wisely, and are geared toward making cities smarter. It is imperative that we embrace the latest and most cutting-edge solutions, as well as the innovative and environmentally sustainable applications, and services linked with these technologies [12], [13].

In a prototypical smart city ecosystem there are different types of sustainability [33], depicted in Figure 4 and discussed below:

1) INHABITANT SUSTAINABILITY

The level of social engagement, openness to many communities, expansion in human capital, education, and diminishing digital gap characterise the sustainability of clever city dwellers. Addressing the current and future demands of the population, delivering equitable opportunity to all, and the perceived safety to promote a smart city's sustainability [41].

2) GOVERNANCE SUSTAINABILITY

The commitment of citizens to decision-taking, co-creation and use of various common tools, technological convergence, and information exchange facilities to achieve improved QoL facilitates governance sustainability. For stable administration in a smart city, the convergence of administration with larger society problems is essential [42].

3) POLICY SUSTAINABILITY

The pursuit of technical innovation is considered a vital aspect of the sustainability of policies. Theoretical solidity, scientific utility, social intelligence, environmental invention, and relevance within and across borders distinguish the sustainability of intelligent urban strategies [43].

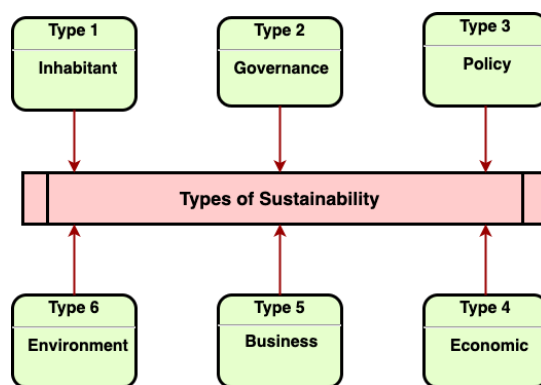


FIGURE 4. Smart cities: Types of sustainability.

4) ECONOMIC SUSTAINABILITY

The economic viability of a smart city is linked to the growth of a business climate that attracts new firms. The financial performance of the smart city is recognized by factors like invention, price stability, creativity and self-sufficiency, as well as the world wide expansion of the local economy [44].

5) BUSINESS SUSTAINABILITY

In order to provide healthy, ethical and lasting industrial growth, the sustainable development of an intelligent city is assisted by management and coordination of economic, environmental, and social demands and issues [45].

6) ENVIRONMENT SUSTAINABILITY

Environmental sustainability in an intelligent town requires natural resource conservation and safeguarding of natural habitat, through effective use of resources. Clean water shortages, depletion of air quality, diminished natural reserves, and ecological imbalances must be combined with state-of-art technological solutions for smart cities [46]. Adopting sustainable development practices is absolutely essential for smart city initiatives [47]. Smart cities have benefited from an increase in big data due to IoT devices, resulting in greater efficiency in monitoring and prevention. To monitor and address the various issues, there is a need for visualization approaches. To help reduce potential hazards, such as fires, leaks, and so on, smart cities need to use monitoring systems that give decision makers with valuable information. Nevertheless, even though big data originates in real-time, visualization has been a difficult challenge. Even complicated dashboards that include data from several natures are difficult to comprehend without a good visualization methodology.

F. INTERDISCIPLINARY AND TRANS-DISCIPLINARY APPROACH

Research within varied domains has grown steadily in popularity, joined by an increasing volume of papers on interdisciplinary and trans-disciplinary approach [1]. The multidisciplinary nature of the field of sustainable smart cities is just like the research in and on this field. Any assessment

and compilation of this information is therefore multidisciplinary, as it relies on ideas and methods from other sectors [48]. These disciplines include city development, urbanization, geography, and the science of sustainability. However, the influence of heterogeneous attempts on theory building is limited, despite interdisciplinary efforts. In sustainable, intelligent and smarter city research, multidisciplinary, interdisciplinary and trans-disciplinary methodologies and tactics are natural [6], [38], [49].

Corporate governance primarily addresses the issues related to the functioning of the enterprises. Bigger challenges such as business ethics throughout supply chain, civil rights, bribery, and environmental issues are the main concerns of our time, which are progressively cross-referencing the unique worlds of company management. As a result, the merging of governance with such broader societal problems has become increasingly important in the work of sustainability [42].

The real-world awareness realized by sensors by integrating the physical world with the virtual world, that is smart infrastructure, is made possible due to the constant real-world monitoring in an automatic manner. Real world data provides intelligent applications and services. Gaining fresh insights provides the possibility of discovering new ways to create more value through cross-industry synergy [29]. Sustainability is a frequently used word that has been more and more prominent in recent years in urban planning, housing and policy. Debates on sustainability no longer view it just as an environmental concern, but also take economic and social factors into account. While a social dimension of sustainability is commonly understood, precisely what this implies has not been defined or agreed clearly [41].

In the remaining of this paper, Section II is focused on the related work and objectives. Section III highlights the cyber physical aspect of sustainable smart cities. Various application domains in a smart city framework are briefed in section IV. Section V and Section VI discuss the role played by various computational and communication technologies in the deployment of smart city services. Section VII revolves around various top ranked smart city deployments in the world. Security issues associated with various application domains are explained in Section VIII. In Section IX and Section X, authors describe the different challenges faced in the deployment of sustainable smart city services and existing solutions. Finally, the paper is concluded in Section XI by highlighting the future research directions in the domain.

II. RELATED WORK

Researchers, academia and industry have put huge efforts in the last few years for sustainable development of smart cities. Advanced technologies are integrated in the various domains to benefit the residents and other stakeholders. Many surveys are carried out to characterize the role of technology in the various domains of smart cities, sustainable development, security, applications etc. Some authors also

conducted dedicated reviews on sustainable development in smart cities.

In the work carried out in the years 2016-2021, in [50], authors discussed the various problems and risks aroused due to urbanization. It is also highlighted that these challenges can be best administered in the smart city environment. According to the authors, security of the residents, healthy living environment, well connected applications, and sustainability are the fundamental aims to develop smart cities. With the integration of the ICT, two main technological features added into smart city infrastructure are sensing and automation of the different services. Smart cities are analyzed from three fundamental aspects, i.e. technologies deployed, community, and the residents. Smart city model comprises amalgamation of the advanced technologies in the various functional domains. Authors described smart cities as the combination of smart economy, smart mobility, smart living, smart governance, smart education, connected environment, etc. Traffic management and healthcare facilities are presented as two major challenges in the smart city framework. Sustainable transport and green environment are highlighted as the main opportunities in this survey.

In [51], authors conducted a survey on the security aspect in smart cities. Smart commerce, smart environment, smart governance, smart communication and smart mobility are discussed as the major constituents of a smart city framework. Security of information is of prime concern in the smart city environment. Authors characterized the dependence of information security on three main factors: technological factors, governance factors, and socio-economic factors. Technological factors comprise sensors and IoT, communication technologies, data storage, and computational technologies, etc. Governance factors constitute infrastructure, health, education, transport, environment, and energy. Socio-economic factors consist of privacy, business, finance and commerce. To facilitate the residents with a secure city environment, security challenges need to be identified and managed in all the three aspects in a smart city framework. Authors highlighted data confidentiality, integrity, authentication, non-repudiation, and freshness of information as the main goals to be achieved in the context of information security in a smart city environment.

In [52], authors carried out a review to explore the role of various communication technologies in enabling the communication among different smart city devices. Authors characterized these technologies as future and emerging technologies, and modern communication technologies. Along with, IEEE wireless technology standards, main objectives of these technologies, network classes, and mode of operations are also discussed. Authors also presented a case study on four different smart cities i.e. Barcelona, Stratford, Singapore and Porto to describe the role played by communication and networking technologies. Inference management, scalability, interoperability, mobility management, and high energy consumption are the major

challenges faced in the deployment and operation of these technologies in the smart city framework.

In [53], authors investigated the relationship among smart cities and environmental sustainability. Different frameworks, models, and tools related to these two themes are explored in detail. To assure sustainable developments in the smart cities, a number of points need to be taken care of. One important aspect is efficient resource management and utilization in the domains of transportation, healthcare, industry, recreational processes, energy production and distribution, etc. Sustainable development also aims to raise awareness among the residents for the utilization of natural resources.

In [54], a detailed review is conducted by the authors in the domain of smart cities. It was discussed that a huge number of smart devices are used in a smart city framework. Authors characterized the fundamental aspects of the smart cities into two main categories, i.e. components and specifications. The role of IoT in smart city framework is presented describing Radio-Frequency Identification (RFID), Near Field Communication (NFC), Low Rate Wireless Personal Area Network (LRWPAN), ZigBee, Wireless Sensor Networks (WSNs), Dash7, 3G, etc. Authors also discussed smart homes, smart parking, weather forecasting, smart healthcare, smart environment, etc. as various IoT applications in the smart city environment. Heterogeneity, security and privacy, reliability, DR barriers, legal aspects, and huge volume of generated data are highlighted as the major challenges in the IoT facilitated smart city deployment.

In [55], authors raised the issue of rapidly increasing population in urban areas, which initiates the need for a smart and sustainable environment to provide a better QoL to the residents. To achieve this aim, a huge number of sensors and smart devices need to be integrated in the infrastructure. There is also the need for suitable communication technologies for the efficient deployment of various smart city applications. Different types of communication technologies are available to connect the various devices in a variety of smart city applications. In this work, authors discussed different types of sensors deployed, and communication technologies used in various smart city domains.

In [56], smart city is introduced as a multidimensional concept, and smart city governance as one of the relatively less explored areas. Author expressed his opinion on the availability of multiple definitions of smart city governance. Stakeholders, processes, legislation and policies, structure, role, and responsibilities are the main participating components of smart city governance.

In [57], authors carried out a survey and discussed the various benefits and issues faced in the smart city environment. Various features to characterize a city as a smart city are also presented in this paper. A major reason for the development of smart cities is the volume of population living in urban areas. The United Nations is expecting around 6 billion people living in urban areas by the year 2050, which requires a high degree of resource optimization in the cities.

Due to this huge volume, a variety of issues are evolving in the various domains like transportation, infrastructure, healthcare, education, water and waste management, energy distribution, and many more. These all are the major issues to be addressed in the smart city environment. Authors discussed the advantages of smart city framework in planning and development, e-governance, economical development, better services, water and waste management, energy production and distribution, smart buildings, etc. Major challenge faced in the deployment of smart cities is the unavailability of the right infrastructure, needed resources, and desired skill set. Seattle-US, Helsinki- Finland, Barcelona- Spain, the Island City State- Singapore, Songdo-South Korea, Milton Keynes-UK are discussed as some of the best smart cities in the world.

In [58], authors highlighted that the concept of smart city emerged to administer the various challenges evolved due to huge growth of urbanization. They highlighted IoT as the parent technology in the development of smart city framework. In this review, sustainability, smartness, QoL, and urbanization are presented as the main features of the smart city environment. General architecture of the smart city environment is discussed in detail. Smart healthcare, smart warehouse, smart factory, smart grids, smart community, smart transportation, and smart hospitality are characterized as the major constituents of the smart city framework. Authors highlighted development and operational cost, heterogeneity of devices, information security, and huge volume of data for collection, processing and storage, and sustainability as the major challenges in the smart city environment.

In [59], authors impressed upon the rise in comfort level of the residents due to the integration of ICT in various day-to-day activities in a smart city environment. Authors presented the definition of the smart cities from the aspects of technology, domain, integration, and data. Different application areas, like smart buildings, smart healthcare, security of information of all the stakeholders, administration, smart economy, smart living, and smart transportation are discussed by the authors. These areas are further classified as business-oriented applications, citizen-oriented applications, environment-related applications, and government-oriented applications. A case study is also presented on a few cities which have either been transferred to smart cities in the last decade or critical areas have been identified to work upon to shift the paradigm to the smart cities.

In [60], authors highlighted ICT as the main reason behind the revolutionary development in the domain of smart cities. Various advanced technologies, like IoT, cloud computing, and big data are also playing crucial roles in the different domains for progress and optimal resource utilization. Authors presented smart living, smart people, smart mobility, smart administration, and smart economy as the main domains in the smart city environment. In this analysis, the concept of smart floating cities is introduced. The need for sustainable smart floating cities is stressed upon.

It has also been observed that the population is increasing rapidly in the seafront areas.

In [61], authors discussed the various issues faced nowadays in the modern cities in the context of population, unavailability of the needed infrastructure, pollution, traffic, etc. It is emphasized that the concept of smart cities is introduced to address these challenges, and facilitate a sustainable environment to provide comfortable living to the residents. Smart city framework is expected to cater smart and intelligent solutions to address complex urban challenges. In this paper, authors carried out a review on different Smart City Assessment Tools to analyze the strength of different smart city projects. These tools use different performance indicators to measure the benefits which will be catered to different stakeholders in different domains. Authors highlighted the role of these assessment tools in different decision making tasks related to smart city projects.

In [62], authors discussed the state-of-art hyper-connected smart city concept. These types of smart city frameworks are devised to cater better quality life, controlled information dissemination, and developing sustainable environments. In this paper, authors reviewed the various privacy and security challenges in the area of big data collection, storage, and processing in various smart city applications. Different types of attacks devised on various application areas are also discussed.

In [63], authors reviewed the vital role played by IoT in the smart city environment. It automates the amalgamation of different technologies and devices in a smart city environment by limiting the need for human intervention. By acting as a base for the integration of the other advanced technologies, it contributes toward comfortable and sustainable living for the residents. Smart transportation, smart agriculture, smart services, smart energy, smart infrastructure, smart homes, smart health, and smart industry are the main domain in a smart city framework. The role of cloud computing, edge computing and fog computing to manage and process data collected through various IoT devices in a smart city environment is discussed and compared. Authors highlighted the security and privacy, heterogeneity of smart sensors, networking, and big data analytics as the major challenges in the deployment of IoT in a smart city environment. Various sensing technologies used in the different application domains in a smart city are also discussed. Different types of security threats are also presented in this review.

In [64], authors conducted a survey to study the impact of various smart city technologies on the behavior of the residents. This study was conducted from the aspect of technical meditation, a relatively new concept introduced in the domain of smart cities. The model considered for this study was Dorrestijn's model, devised to explore human-technology interactions. Authors categorized the impact of human – technology interaction in four different types of technical meditation, i.e. to-the-hand, above-the-hand, before the eye, and behind the back. Fundamentally, this study was

carried out to identify the social and ethical issues evolving in the smart city framework.

In [65], authors impressed upon the various challenges like huge population, limited resources, pollution, etc. evolving with urbanization. The issues related to the security of the residents/information and sustainability also needs to be taken care on priority. IoT is presented as one of the most fundamental technologies in the development of smart cities. Authors carried this review to highlight the role of IoT to manage various infrastructure related projects for better results. Detailed IoT framework is presented in this work. As many of the smart city applications are using cloud infrastructure; so, deployment of cloud technology in IoT applications is also described in detail. Various smart city projects are usually multidimensional. Mobility, economy, people, living, environment, and governance are presented as the main characteristics of the smart city framework. Authors also discussed some applications of smart cities in this article.

Comparative analysis of all the surveys discussed above, is summarized in Table 1. The parameters considered for the comparative study are the computational and communication technologies, cyber physical aspect of smart cities, applications, sustainability and challenges, and security issues. While studying existing literature, it has been observed that in none of the survey papers, all the aspects mentioned in Table 1, are reviewed together and completely, which is the novel contribution of this work. This paper is aimed to discuss:

- The architecture, cyber physical aspect, and sustainability goals in a smart city ecosystem.
- The role of various computational and communication technologies in the deployment of sustainable smart city services and the challenges.
- Security issues in smart city framework.
- Various challenges in the sustainable development of smart city services and existing technology-based solution.

III. CYBER PHYSICAL ASPECT OF SUSTAINABLE SMART CITIES

A Cyber Physical System (CPS) is a convoluted, composite and distributed system consisting of a deep integration of cyber components and physical mechanisms [66], [67]. A variety of cyber components, like sensors, actuators, and control systems etc. are deployed in a smart city framework for the sustainable development of various domains [68], [69]. Different physical mechanisms comprise various operations performed in a smart city environment; few examples are traffic management, security, water and waste management, temperature control, etc. A CPS can also be termed as an integration of smart computational devices, communication networks, and physical processes to observe and administer the natural environment. For the sustainable development of smart cities, its infrastructure consists of sensing the data through various smart devices, communi-

TABLE 1. Comparative analysis of existing surveys and proposed work.

Authors	Year	Computational Technologies?	Communication Technologies?	Cyber Aspect?	Physical	Applications?	Sustainability?	Security Issues?	Challenges in the Development of Sustainable Smart Cities?
Arroub et al. [50]	2016	No	No	No		Yes	Yes	No	Yes
Ijazet al. [51]	2016	No	Yes	No		Yes	No	Yes	Yes.
Yaqoob et al. [52]	2017	No	Yes	No		No	No	No	No
Trindade et al. [53]	2017	No	No	No		Yes	Yes	No	Yes
Talari et al. [54]	2017	No	Yes	No		Yes	No	Yes	No
Ruhlandt [56]	2018	No	No	No		No	Yes	Yes	No
Okai et al. [57]	2018	No	No	No		Yes	Yes	No	Yes
Silva et al. [58]	2018	No	Yes	No		Yes	Yes	Yes	Yes
Corcuera et al. [59]	2019	No	No	No		Yes	Yes	No	Yes
Kirimtat et al. [60]	2020	Yes	No	No		Yes	Yes	No	Yes
Patraoet al. [61]	2020	No	No	No		No	Yes	No	Yes
Naqvi et al. [62]	2020	No	No	No		Yes	No	Yes	No
Syed et al. [63]	2021	Yes	Yes	No		Yes	Yes	Yes	Yes
Voordijk and Dorrestjin [64]	2021	No	No	No		No	Yes	Yes	Yes
Hassan et al. [65]	2021	No	Yes	No		Yes	Yes	No	No
Our Work	2021	Yes	Yes	Yes		Yes	Yes	Yes	Yes

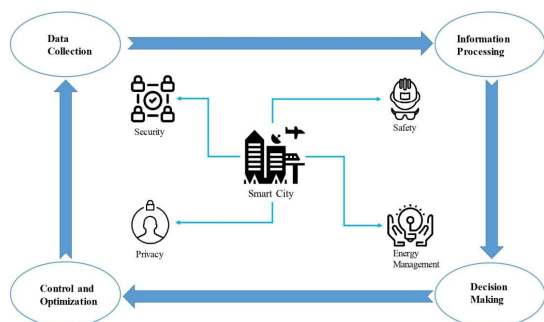


FIGURE 5. Smart city: The CPS components.

ation, processing, analysis and decision making [70], [71], which requires an equitable compassion of “physical” and “cyber” segments, depicted in Figure 5. A balance among two components contributes to the security and privacy aspects, safety and suitable energy management required in the wireless smart city environment [72].

In the smart city framework, a number of CPS operates in parallel facilitating the functioning of various smart city domains, depicted in Figure 6. The coexistence of multiple subsystems is the main reason behind the unavailability of a standard framework to manage whole system as a unique entity, which is the root cause of various challenges discussed below:

A. ADMINISTRATIVE

A smart city framework is owned by various stakeholders, i.e., public, private, and others, who want to make their own decisions in their domains.

B. TECHNOLOGY REVOLUTION

Rapid technological revolution is also one of the main reasons to limit the whole system as a single CPS entity.

C. INCOMPATIBILITY

Incompatibility among the previous and new technologies in the smart city environment is also a limiting factor in the successful deployment of CPS.

One possible solution to address these issues is CPS federation; practiced by many researchers working in the domain of smart cities. It facilitates the management of smart devices, actuators, and other resources, which help to realize various smart city services.

IV. APPLICATION DOMAINS IN A SMART CITY FRAMEWORK

In the smart city framework, smart computing is used for a variety of vital infrastructure components and services. Smart Computing technology deployed in smart cities, is used by civic leaders to improve operations and services for constituents. some of the prominent real-life applications of the smart city are discussed below [74]:

A. CITY ADMINISTRATION-STREAMLINED MANAGEMENT

In order to prosper in today’s modern service-based economy, competent municipal management must provide appropriate services to its residents. The intelligent use of municipal governance services makes people aware of the city’s state and is capable of serving the people effectively [75]. Communication and cooperation technologies are used in this context to facilitate city operations. A city administration complex deals with various aspects of life, such as healthcare and education. Also, it supplies dependable infrastructure, which is provided by green buildings, transportation, and utilities that are efficient.

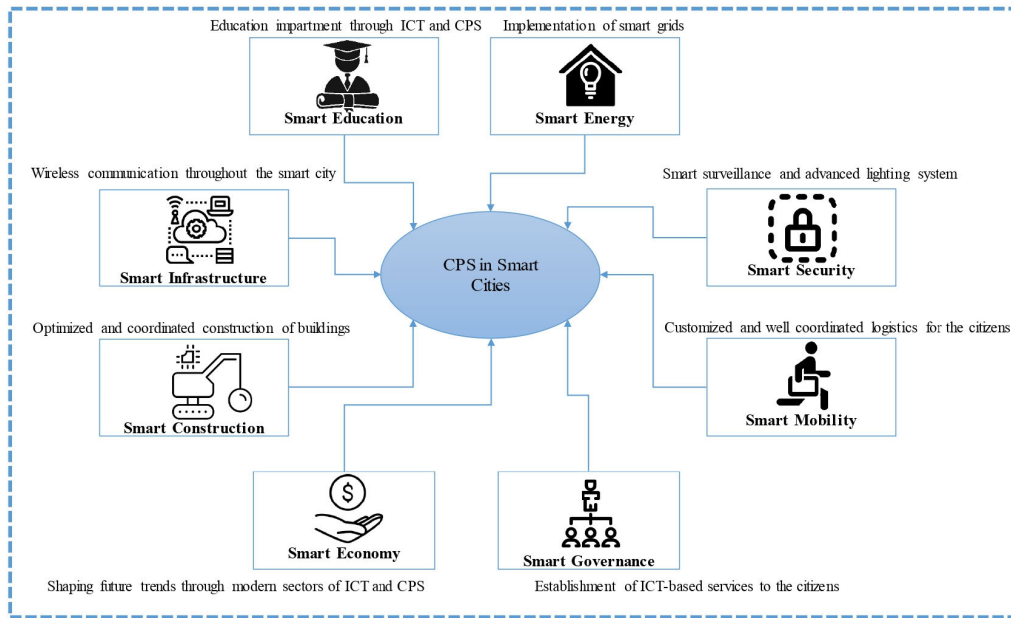


FIGURE 6. CPS deployed: Smart city domains [73].

B. EDUCATION CAUSES INCREASED ACCESS, QUALITY IMPROVEMENT AND COST REDUCTION

The use of educational technology will have numerous benefits, including improved access, better services and lower prices [76]. PCs and the internet, for example, improve access to education for children who can't attend full-time schools or reside in rural areas. Convenient, lower cost and higher quality learning are some of the benefits that digital material and collaboration technology offer.

C. SMART HOMES

Intelligent homes and intelligent cities emerge to address an expanding urban world dealing with restricted resources and a way to expand energy efficiency. Intelligent cities are helping to deal with overcrowding and wastage of energy, while improving the QoL. Smart homes will gain from IoT to increase energy efficiency, safety and convenience by introducing smart, connected gadgets [77].

D. SMART BUILDINGS

A smart building is the key component of any intelligent city. Smart buildings drive innovation and IoT to address common difficulties in building management. All systems - power, illumination, water, lighting, emergency services, and security - are connected to a smart building [78].

E. HEALTHCARE-INCREASES AVAILABILITY AND MAKES THE DIAGNOSIS MORE ACCURATE

A scalable storage system and a communication platform create a smart healthcare system. Patients' records can be maintained, exchanged, and transmitted all across the world

with this type of IT foundation. Not only is this data used for disease diagnosis, but it also serves as the foundation for future studies. Emergency services are made ready to respond quickly via communication networks. Remote medical services are available to patients who aren't able to travel. This facility is provided using videoconferencing technologies [79].

F. PUBLIC SAFETY USE INFORMATION IN REAL TIME TO RESPOND QUICKLY TO DISASTERS AND THREATS

The number of people that live in a town necessitates an increase in the responsiveness of the police, fire, and other public safety employees, as well as in the general level of crime. Public security plans are inventive worldwide by employing modern communication technology to connect fire department and police department to information in real time [80].

G. OPERATING EXPENSES ARE LOWERED, ASSET VALUE IS INCREASED, AND OCCUPANCY RATES ARE IMPROVED IN REAL ESTATE

Numerous financial and environmental benefits are delivered by smarter property; from office towers to production facilities to shopping centers and residences of the citizens [81].

H. TRANSPORTATION- REDUCE CONGESTION IN TRAFFIC WHILE PROMOTING PUBLIC TRANSPORT

Improved public transit alternatives, such as speedier and more convenient services are already on the road maps of many cities to help them minimize traffic congestion and associated financial and environmental costs [82]. However, these projects will demand a substantial investment of

money and time. The prices offered by intelligent computing technologies can act as an intermediate measure to collect funding for new public transport and encourage the use of existing public transport.

I. SERVICES-USE AS MUCH POWER OR WATER AS NECESSARY TO MINIMIZE WASTAGE

Utility infrastructure is made up of a well-functioning system and an innovative strategy for providing water, gas, and electricity [83]. In order to deal with limited resources, implementing smarter strategies for conserving, delivering, and managing energy is vital. Smart grids are increasingly implemented around the world.

V. COMPUTATIONAL TECHNOLOGIES IN SMART CITY SUBSYSTEMS

The term “smart city” presents a complex framework [84]. It is not possible to describe the entire smart city environment and infrastructure with single definition [85], but different definitions are given by the authors to cover the various aspects. In 2009, Caragliu defined smart cities on the basis of information and communication infrastructure, economic development, efficient natural resource utilization, quality of life, etc. [86]. In 2008, Hollands presented the smart city framework focusing on modes of data transfer, political and social changes [84]. Smart city is a framework in which different types of technologies are amalgamated in different applications to assure the economical development, better health of the residents and sustainable solutions. The concept of smart city deals with the development of urban infrastructure with the integration of technology to encourage economic and social development. A number of technologies are integrated across the different domains such as healthcare, transportation, education, security, etc. to achieve the fundamental goals.

A. INTERNET OF THINGS (IoT)

Nowadays, the term ‘IoT’ is becoming very recurrent in our daily life. It has been amalgamated in a number of routine life tasks, and impacting our interaction with the environment and our activities. In the framework of IoT, every physical thing is assigned with a label and connected in cyberspace [87]. These labels uniquely identify the smart things in the global network. All the smart devices can interact with each other over the network they are deployed in [88]–[93]. IoT framework comprises users, devices, technologies, storage, processing, and analysis of data. The fundamental objective of IoT devices is to connect anything, anybody, anytime, any network, anywhere [84]. The usage of IoT is making it convenient to solve simple to complex problems in various developing and developed countries [94]–[96]. IoT has a number of applications in various domains, like manufacturing, transportation, retail, healthcare, supply-chain, agriculture, energy, and buildings etc.

The rapid development in the domain of IoT is causing the emergence of a number of new concepts into phenomena [97].

Among various evolving concepts, smart cities are one of the prominent ones [98]. In the IoT-facilitated smart city framework, a variety of smart devices deploy different services to realize bizarre agility and efficiency in different aspects of urban life [99]. Different modernized services, i.e., smart homes and buildings, automated transportation, smart energy, smart healthcare, smart factory, smart energy production, and dissipation are exigently enhancing the quality of human life in an IoT-based smart city environment [100]. In an IoT-facilitated smart city framework, different services are supported by enormous IoT devices and remote servers. Services catered in smart cities range from video-surveillance to virtual reality, smart healthcare to water and waste management, and may have very extreme quality parameters [101]. Different IoT-integrated services make the lives of the residents comfortable by assuring sustainability of the services [87], [93], [97], [102]–[105]. To efficiently support these services, the volume of IoT devices is increasing exponentially in terms of number and variety. IoT devices deployed to cater different types of services can be categorized as stationary and mobile [97]. Stationary things devised at various locations need to be supported by heavy duty processing units and storage capacity [106]. On the other side, mobile devices are facilitated with limited resources in terms of processing, storage and energy backup [107].

Due to the huge volume of smart devices, variety of services and number of quality of service parameters, efficient resource allocation for the successful functioning of different applications to provide a comfortable life to the residents is the biggest challenge faced in the smart city framework. There are many other challenges faced in the deployment of IoT equipped applications in a smart city framework, discussed below:

- Different information systems used to generate data in smart cities usually provide static data. Dynamic analysis to fasten the process of decision making in urban environments becomes difficult with such data. So, there is an urgent need for suitable information systems to cater data to real-time IoT-based applications with the competence to manage and process data from multiple IoT equipped applications.
- Another major challenge faced is the variety of sensors used in different IoT-based devices in smart city applications. These sensors are heterogeneous from the aspects of range, surface area, speed, storage etc., and the applications where they can fit in. Data captured from heterogeneous environments becomes difficult to manage and process.
- In a smart city framework, a huge volume of spatial data is gathered using sensors deployed in different applications. Both structured and unstructured data is generated from a diverse range of applications. Management of structured data is very convenient. But, unstructured data like audio files, pictures and videos are challenging to store, process, analyze and transfer.

B. ARTIFICIAL INTELLIGENCE (AI)

Artificial Intelligence (AI) is one of the most important technologies amalgamated in different application areas in smart cities [85], [108], [109]. It plays a very vital role in the development of smart cities [81], [82], [110]–[115]. The concept of AI was evolved in the year 1979 [116]. It was introduced by John McCarthy, as a domain to design and develop intelligent machines [117]. These intelligent machines can portray human actions, like learning, decision making, problem solving, etc., in various smart city application domains. AI as a domain, is the amalgamation of many other fields, like computer science, mathematics, psychology, and neuroscience. AI is characterized by different authors with different taxonomies covering different aspects. AI is a facilitating sub-part of the computers to provide competence to behave intelligently. AI is also termed as a super system which can function without externally being programmed. In [118], authors described the role of the technology in efficient utilization of the natural resources in the smart city framework. Authors in [106], discussed the vital contribution of AI technology from the security aspect, i.e., to administer different types of frauds and criminal activities. Since the year of its inception, AI has gone through many cycles of ups and downs of its popularity with slow development. But as discussed above, it has become enormously successful in the smart cities by developing different types of intelligent systems. It has already contributed in the areas of transport [119], public safety [120], education [121], cybersecurity, human resource management, healthcare, tourism, smart homes, agriculture, energy, waste management, industry, and many more [116], [122], to solve complex problems in a smart city framework. Not only in various application domains, but AI is also playing a very vital role in the planning, design and development of the smart city frameworks [123]. This pivotal technology can also be utilized to secure smart city residents from the effect of natural disasters and pandemics developing intelligent sub-systems, applications, and services [124].

Besides the important role played by AI in smart cities, it also faces some challenges discussed below [115], [125]:

- Although AI is contributing vitally in different data processing applications, but it's appliance becomes difficult in the domains where data are not smoothly available or can be gathered.
- AI algorithms are very efficient to solve complex problems, but are complex by nature to implement on available dataset gathered from a heterogeneous environment.
- AI systems are also limited by ethical, social, and legal challenges due to the facts of human behavioral simulation, unemployment caused as intelligent machines replace human resources, and unavailability of legal policies for intelligent systems respectively.

C. BLOCKCHAIN

Blockchain is defined as a decentralized ledger technology [126], [127]. The concept of blockchain was introduced

with the evolution of bitcoin in the domain of crypto currencies. It can be applied to any type of transaction. Blockchain is a publicly accessible common database [128], which facilitates reliable, transparent, and secure transactions in a variety of application domains [129]. Some of the real life applications of the blockchain technology in the areas of international payments, exchange of crypto currency, storage and distribution of medical data, banking and finance, supply-chain and logistics observations, real estate, etc., are among the prominent ones.

A huge volume of data is generated in the different application domains of smart cities [130]. To manage the voluminous amount of data, there is an intense requirement of reliable data transfer platforms with minimal communication delays. In this type of environment, all the stakeholders must be sure about the validity of data for its originality and the identity of the object from which it has been received. Validity of the data must be ensured for least communication delays when the volume is huge in real-time applications. Data generated and exchanged in most of the applications in smart city framework are sensitive; so, privacy becomes the fundamental requirement. Previously practiced techniques to ensure data integrity in smart cities were facing the various challenges, mentioned below:

- Dependency on centralized stakeholders and entities responsible for data generation.
- Lack of privacy.
- Data stored using traditional centralized approaches which are easily vulnerable to different types of attacks.

Blockchain has been proven a propitious technology in the domain of smart cities, which has efficiently administered the aforementioned issues. It aids to assure security and privacy of data generated from various applications stored in decentralized frameworks [131]. With the proper use of blockchain technology, transparency can be enhanced congenitally. Physical infrastructure, institutional infrastructure, and social and economic infrastructure are considered as the basic supports of a smart city framework [132]. Blockchain technology is required to provide robust, secure, transparent, and valid solutions to secure data [133]. A number of blockchain applications covering various aspects in various verticals are already given by the researchers. Blockchain technology plays a very vital role to enhance the security and privacy of data in smart e-commerce, electronic voting, smart transportation, healthcare, smart grids, supply-chain management, smart homes, and property management in urban environments [134]. Although blockchain technology is securing data in various applications in smart cities, few challenges are faced in its deployment in various domains [135]. Blockchain components are deployed at multiple levels in any security solution, which face following challenges:

- Cryptography is used as the key technique to secure distributed data in blockchain solutions. But the process of key generation and verification, and digital signatures are subject to vulnerabilities.

- As blockchain applications are distributed by nature, communication delay is the main challenge faced in these solutions. Communication delay depends upon the data transfer rate and size of the network. Transfer of blocks is limited by consensus, propagation delay, forking, etc.
- Although most of the IoT nodes are reliable and validated in blockchain solutions, they have different computational power in a smart city environment.
- Varying block size and transaction validation time in different applications is the major issue faced from the scalability aspect.
- Node trust and identification are the main challenges faced in decentralized blockchain solutions to make them global like the internet.

D. BIG DATA

Nowadays, a huge volume of data termed as ‘Big Data’ is generated practically in all the domains of human activities. In size, big data is far beyond the previously generated data in volume, and is calibrated using Petabytes and Exabytes [136]. This big aspect of generated data is described in terms of variety, volume, and velocity of generation [137]. Such a voluminous amount of data is processed using different analytic tools and techniques for knowledge discovery and extraction of facts. Analysis of the generated data opens new doors to interpret the digital world. Availability of voluminous data aids the process of decision making. Along with big data, other technologies like, AI and ML are integrated to train the computers to clone human behavior for decision making [108]. To obtain more accurate results, more real time data is required for various machine learning algorithms.

In a smart city environment, a huge volume of data is generated on a daily basis in various application domains. This data is many folds greater than the data generated in traditional cities, and become the base of the various services deployed using various technologies. This voluminous amount of data provides a platform to understand beneficial comprehension related to various smart city operations and application domains. Usually big data gathered in a smart city environment is unstructured, as collected using different types of smart devices and sensors implanted in various smart applications. Although it is more challenging to organize, process and analyze huge volumes of unstructured data, it is playing a very prominent role in smart cities to improve the environment, economy, public health, transportation, security, governance, quality of life, sustainability, etc. [18], [47], [138]–[142].

In spite of playing crucial role to improve the quality of services delivered to smart city residents, a few challenges are also faced in big data analytics in smart city framework [143], discussed below:

- Data are gathered using a variety of sensors installed in different application domains functioning in very

diverse environments. Integration of this data in the IT domain is a very challenging task.

- In a smart city framework, almost everything is connected in cyberspace, i.e., the internet. As different types of devices are connected in this environment, there are many risks associated like, security of information, unauthorized access, vulnerable smart devices and communication networks, weak pairing of things, etc., Consequently, there is a requirement of more standardized security protocols.
- Data gathered through various sensors and devices is unstructured which is challenging to store and process.

E. CLOUD COMPUTING

Cloud Computing is one of the prominent technological paradigms that became popular in the research industry in the last few years [144]. It encourages the availability of different types of software and hardware resources in cyberspace which can be utilized as per requirement [145]. Cloud services are characterized as Software as a Service (SaaS), Infrastructure as a Service (IaaS), Storage as a Service (STaaS), Network as a Service (NaaS), and Platform as a Service (PaaS), named according to the type of resources provided via cloud. Fundamental aim of cloud computing is to cater reliable and better quality services economically. Cloud computing framework is generally used to offload huge volumes of data for storage and processing, gathered in different applications.

City administration is a relatively diverse and complex system which is the fundamental reason for the integration of cloud computing. Even on account of limited resources, a range of services are provided to the residents [144]. In smart cities, cloud computing aids to dispense better quality services to the residents in multiple verticals [146]–[148]. Different types of services are evaluated in terms of latency, energy consumption, throughput, computational requirement, volume of data to be transferred, and storage requirement. QoS can be characterized as a function of above parameters [149].

Cloud computing is facilitating in the domains of smart citizen services [150], mobility, healthcare, disaster management, tourism, energy [151], waste management [149], education, municipal services, governance, smart buildings and homes [152], security, and transport route planning [148] to deliver quality services to the residents.

Along with benefits, the appliance of cloud computing in smart city applications is also limited due to different issues, discussed below:

- In smart cities, a variety of sensors and IoT devices are used to gather data in different applications. But there is a lack of appropriate IoT-Cloud confluence mechanisms to leverage the maximum possible benefit of cloud technology in IoT- facilitated applications.

- Security of sensitive data (patient's healthcare records, government policies, etc.). stored on cloud is a major issue to be worked upon.
- Scalability among the cloud platforms provided by different organizations, like Google, Amazon, etc., and smart city cloud applications is also a major challenge that needs to be addressed.

VI. COMMUNICATION TECHNOLOGIES

Communication and network technologies are the backbone of smart city framework to provide uninterrupted connectivity among the residents, applications and services. These technologies also provide a platform to take maximum benefit of computational techniques employed in different application domains. Different technologies are used in the different domains depending upon the coverage, data transfer rate, infrastructure, suitability for the application, etc. Among all the available technologies, few are developed and already integrated in many domains, but some are emerging. Some of the emerging network technologies are listed below:

- Software Defined Wireless Networks (SDWN)
- Network Function Virtualization (NFV)
- Visible Light Communication (VLC)
- Cognitive Radio Networks (CRN)
- Green Communication (GC)
- LowPAN (IPv6 Low-power Wireless Personal Area Network)
- Thread (IP-based IPv6 networking protocol)
- Sigfox
- Neul
- Near Field Communication (NFC)

The main features of the emerging technologies are high data rate, better connectivity, low attenuation, efficient spectrum utilization, scalability, low coverage cost, robustness, authentication, and agile encryption. Although all these technologies are available to facilitate connectivity but SDWN, NFV, CRN, and GC are not useful for smart cities due to low data transfer rate and communication range. There are many other communication and network technologies available to support smart city applications, summarised in Table 2. Advantages and disadvantages of these technologies are also mentioned.

The concept of screen mirroring in wireless technology is widely used to cast one screen to another. In multicast, WiFi provides a better solution. In [153], authors proposed to sink two different screens to one where both screens can be seen at the same time, and can be operated on a multi window android phone. The WiMax is a new paradigm for traditional wireless network systems and it is better radio technology in QoS and security. It is an open IP access based network infrastructure and can be used in different applications. It is used for business customers to use hotspots with mobile and high connectivity. It is known as 802.16 standard. Using this technology, the penetration losses in the building are modeled and noise and interferences are minimized [154].

TABLE 2. Communication technologies for smart city framework: Advantages and disadvantages.

Emerging Technologies	Advantages	Disadvantages
WiFi	·Wireless ·Users are mobile	·High signal attenuation/distortion ·Fixed service radius ·Unstable
WiMax	·High speed internet connection ·Broad coverage	· Costly in installation
LTE	·Compatibility for future ·Proofing reduce the lagging · Efficient in terms of spectrum	· Expensive due to network base stations
LTE-A	·High data rate ·Elevated voice excellence	·Easily accessible ·High cost
Bluetooth	·Easy to install ·Cheap	· Insecure ·Short range communication
Zigbee	·Cheap ·Avoidance of collision ·Power saving	·Slow speed
Z-Wave	·Simpler than ZigBee	·Difficult in movement ·Security flaws
LoRaWAN	·Low cost ·Secure bi-directional communication ·Less power consumption	·Short range communication
5G	·Fastest communication	·Latency

The passive optical network and WiMax are suitable economical solutions for the wider coverage of areas with high speed in a smart city environment. The WiMax minimizes the bandwidth blocking ratio and reduces the network resource consumption [155]. The microstrip dual band planar slot antennas are suitable for the lower range of WAN and higher range of WiMax applications [156]. In smart cities, the IoT equipped WSNs are more effective for collecting data. In the Metropolitan Area Networks (MANs), the WiMAX aids to interconnect sensors up to the range of 50km, for which the communication protocols exist in physical and data link layer [157]. The wireless mobility, coverage, bandwidth, and signal strength are the main features of the 4G networks to provide quality smart services [158]. In smart cities, the owned User Equipments (UEs) communicate with the public service provider LTE networks. LTE systems have name based routing. LTE logical nodes can be delegated to provide close proximity services to IoT based UEs in smart cities [159]–[163].

There is an enormous growth of smart devices using video streaming in the smart cities, which is the main reason for LTE-A's popularity. It is used for High Definition (HD) video Streaming and Noise Ratio (SINR) [164]–[166]. The Bluetooth controlled air cleaner used in smart homes is another application of communication technologies [167]. A fault tolerant smart system to monitor the attendance of students

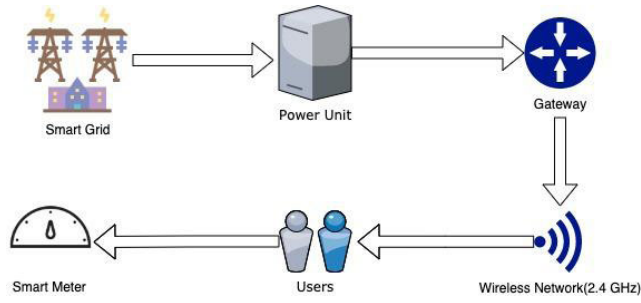


FIGURE 7. Conventional diagram of ZigBee: Smart city applications.

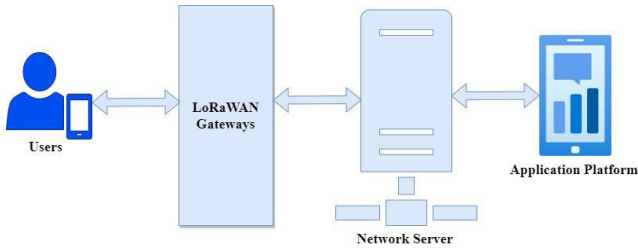


FIGURE 8. Network diagram of LoRaWAN in IoT.

TABLE 3. Telecom generations and features in smart city applications.

Generation	Expectation	Features
2G	Enhanced digital voice quality	SMS
3G	WAP	Web
4G	IMS	YouTube, WhatsApp
5G	IoT with low latency	Wireless world wide web (WWWW)

is an application of Bluetooth Low Energy (BLE) technology in the education sector in smart city framework [168].

The integration of IoT with the smart city ecosystem makes the smart city architecture scalable and can be implemented using BLE. This concept has extended the platform of personal area networks (PAN) to make them intractable in real time [169], [170]. In smart metering systems, the WSN incorporates multi-radio and multi-channel to improve the efficiency of data transmission. The conflux of IoT, WSNs, and ZigBee modulation facilitates the dissipations of power from smart grids to end users [171]–[175], shown in Figure 7.

The Low Power Wide Area Network (LPWAN) facilitates serving massive low power devices simultaneously. The Low Range Wide Area Network (LoRaWAN) supports low range, low power mobile communication for IoT devices in smart city applications. It also aids to design scalable and efficient services in a smart city framework [176]–[182]. The network pattern and its connectivity in the LoRaWAN for IoT is shown in Figure 8.

Different telecom generations used in smart city applications are summarized in Table 3. Among these, the 5G technology is critical to implement due to the diversity in the requirements to realize different applications. So,

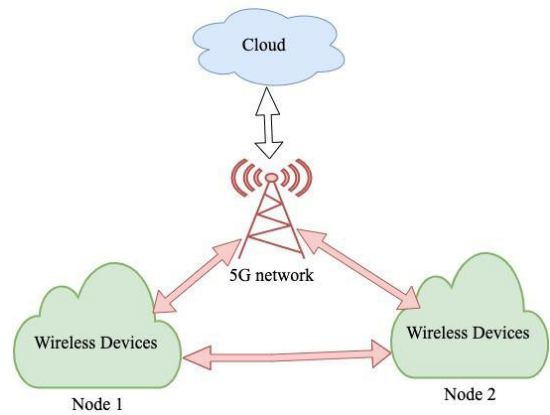


FIGURE 9. Conventional 5G networks in smart cities.

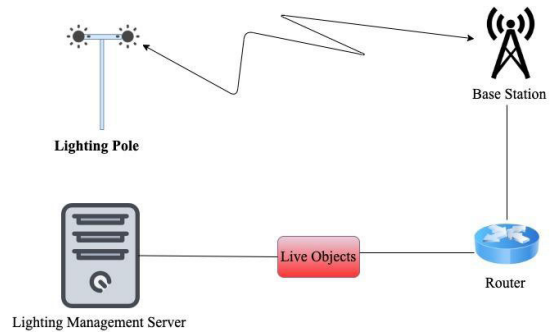


FIGURE 10. Intelligent lighting system using 5G network.

the deployment of 5G technology is the major challenge faced by the mobile operators. The conventional 5G network to implement various smart city applications is shown in Figure 9. Different customized 5G network architectures are proposed by the researchers to implement various smart city applications [183]–[187]. The schematic diagram of an intelligent lighting system for smart cities deployed using the 5G network is shown in Figure 10. Communication and networking aspects of smart city applications are summarized in Table 4. Different smart city applications can be characterized as ad-hoc or infrastructure based, and are centered on PAN, LAN, and MAN. The fundamental aim of communication technologies is to lower the power consumption, support high speed data transmission, and provide error free connectivity and high spectral efficiency in the deployment of various smart city applications.

VII. CURRENT SMART CITY DEPLOYMENTS

A smart city is a conflux of diversified attributes, concepts, and infrastructure. QoL and sustainability are emerged as two most fundamental objectives to be achieved with this trio [58]. Different computational and communication technologies, discussed in Section V and Section VI, have contributed immensely to meet these goals. Various cutting-edge technologies are being used in different city services and applications. Using these advanced technologies, a variety of innovative solutions have been proposed by the people from academia and industry to provide better living and

TABLE 4. Communication networks for smart cities: Various aspects.

Emerging Technologies		
Software Defined Wireless Networking	Network Function Virtualization	Visible Light Communication
Cognitive Radio	Green Communication	6 Low PAN
Thread	Sig Fox	Neul
Near Field Communication	5G	
Modern Technologies		
WiFi	WiMax	LTE
Z-Wave	LoRaWAN	LTE-A
	Bleetooth	ZigBee
IEEE Standards		
802.11	802.15.1	802.15.3
802.15.4	802.15.6	802.16
Network Classes		
WPAN	WLAN	WMAN
Functioning Modes		
Ad hoc	Infrastructure	
Objectives		
Low Power Consumption	High Rate Data Transmission	Error Free Connectivity
Ultra High Spectral Efficiency		

sustainable services in a smart city ecosystem. In [58], authors presented security and surveillance, hospitality, transportation, electrical grids, healthcare, industry, education, resource management, and community development as the important sub-systems of an urban environment, where deployment of smart services can contribute to the living of the inhabitants. IoT is a core smart city technology and playing a very impressive role to provide connectivity among the plethora of smart things in a smart city environment deployed in different application domains. All the major stakeholders, i.e., vendors, users, and manufacturers have started to take interest in the opportunities offered by IoT [98]. Major IoT deployed application in a smart city environment are smart healthcare, lighting systems, smart buildings and smart homes, smart security, smart grids, etc. Proper traffic management with minimal scope of cyber threats is the key concerns in a smart city environment. In [188], authors proposed a secure traffic management system to administer cyber threats on congested roads. An API framework is proposed by the authors to administer the voluminous quantity of data gathered from district administration to provide sustainable energy services [189]. The deployment of IoT integrated bigdata applications in smart city environment have benefitted the domains of healthcare, safety, transportation, agriculture, etc. [33], [190]. In [191], authors proposed a deep learning-based video surveillance model to control COVID-19 pandemic. The bigdata techniques are benefitting in the domains of smart energy management, travel profile identification, etc. AI is benefitting the autonomy of smart vehicles on smart city roads [192], [194]. In [193], authors proposed a blockchain based machine learning model to deploy privacy services. In all the applications deployed to cater various needs of smart city residents, communication technologies play a very vital role. Consequently, current smart cities/projects deployed around the world are leveraging the benefits of advanced technologies in the various functional areas to facilitate

quality living and sustainability. Smart cities are deployed to improve the various functional domains of a city in terms of competitiveness. Different attributes are used to rank the current smart city deployments from the various aspects. In [58], authors discussed the human capital, environment, technology, social cohesion, the economy, urban planning, international outreach, public management, mobility and transportation, and governance as the dominating areas to be counted to classify the smart cities. Using these criteria, 181 cities around the world are determined as the smartest cities. In this list, New York, London, and Paris cities from the countries, USA, UK, and France topped, while Boston, Amsterdam, Chicago, San Francisco, Seoul, Sydney, and Geneva raked among top 10 best smart cities in the world. Some cities topped in one criterion but at comparatively lower level in second and vice-versa, e.g., New York city ranked first in economy whereas London topped in human capital. Some of the famous top ranked smart city deployments in the world [52], are summarized in Table 5.

VIII. SECURITY ISSUES IN SMART CITIES

Smart cities are equipped with high-tech automatic services to enhance citizens' QoL by providing the best possible support in all required areas. This increase in the number of technological facilities has created a threat to personal and public socio life of the residents by promptly leaking data to the third party. People from academia and industry are continuously putting efforts to ensure privacy and data security in various smart city applications. Various security issues in a smart city framework revolve around data security, cyber security, infrastructure security, and smart governance security [195], depicted in Figure 11, and discussed below:

A. DATA SECURITY

Smart cities rely on many devices and components to set up best sensing and surveillance infrastructure, which gather huge volume of data from various sources and stored locally

TABLE 5. Famous smarts city deployments in the world.

Country	Smart City	Smart Health	Dense Sensor Network	Automated Vehicles	Digital Money	Smart Transportation	Smart Energy	Smart Community	Smart Irrigation
United Kingdom	London	✓	X	X	✓	✓	✓	✓	X
United States of America	San Francisco	X	X	✓	X	✓	✓	✓	X
Spain	Barcelona	✓	X	X	X	✓	✓	✓	X
Spain	Satander City	X	✓	X	X	✓	✓	✓	✓
France	Nice	X	✓	X	✓	✓	✓	X	X
Italy	Padova	X	✓	X	X	✓	✓	✓	X
Singapore	Singapore	X	✓	✓	X	✓	✓	X	X
Canada	Stratford	X	X	X	X	X	✓	✓	X
Indonesia	Jakarta	✓	✓	X	X	✓	✓	X	X
Russia	Moscow	✓	X	X	X	✓	✓	✓	X

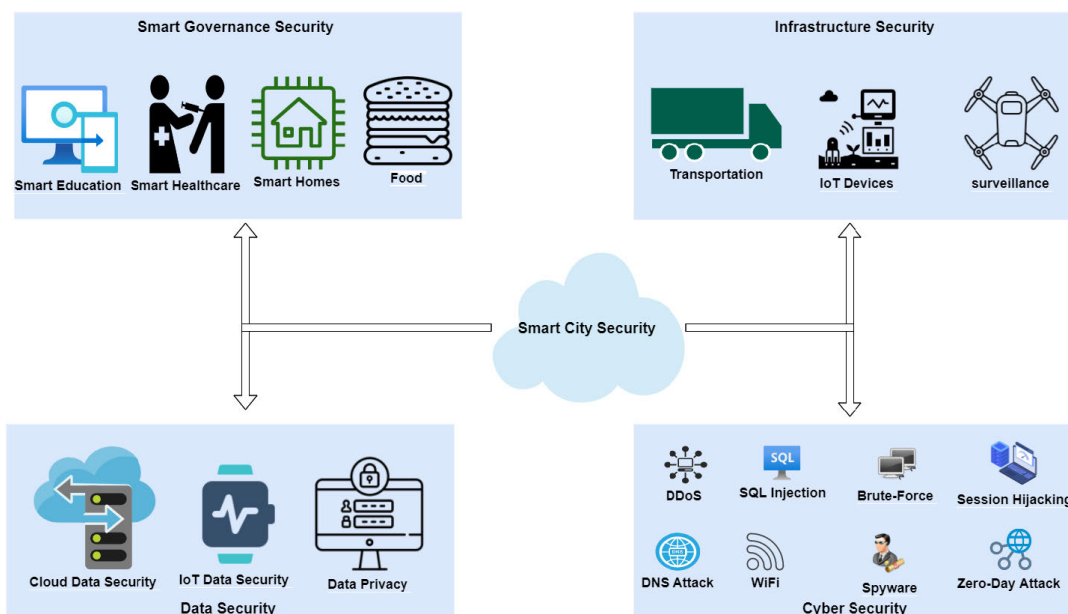


FIGURE 11. Smart city: Security issues.

or remotely. Being a complex system, creating flexible and effective data security and privacy techniques is critical because of the diversity of acquired data and the security levels ranging from personal to public [196]. The domain of data security can further be classified as cloud data security, IoT data security and privacy.

1) CLOUD DATA SECURITY

The process of safeguarding smart city data in a cloud environment, regardless of where that data is housed, whether it's handled internally or externally by a third party, is known as cloud data protection. Securing the data in cloud environment requires a set of rules, controlling mechanisms, and procedures that are used to safeguard data and cloud infrastructure. These security controls protect residents' privacy, and establish authentication procedures for specific users and devices [197]. The requirement of cloud data security is observed as per the need of service/application

and granting permission to access the data for avoiding heavy traffic on cloud servers.

2) IoT DATA SECURITY

IoT devices are always communicating with each other and data servers. To keep all the smart things active and connected to gather data in the smart city environment is a challenge. There is a huge demand of more reliable IoT devices to gather accurate information from the environment. Although it is a tedious task but many countries are not compromising with the quality of IoT devices to capture the correct data [63]. So, the major issue evolving is to secure IoT data, and restricting unauthorized users to get the accessibility. To tackle this problem, several techniques have been proposed, such as hosting sensing data on cloud, local networks, etc.

3) DATA PRIVACY

One of the most significant acts in smart cities is to keep the data private and not accessible to third party. If the data

have been hosted on cloud server, there should be a service level agreement that ensures data accessibility to authorized users only. Due to internet connectivity issues, data may be lost in different smart city applications. Suitable recovery mechanism and techniques need to be designed to administer data losses.

The concept of anytime-anywhere connectivity in the smart city ecosystem has drained maximum attention on privacy -persevering publishing [198]. In an increasingly data-driven society, this issue is becoming very important in the applications where personal data is gathered automatically. In smart cities, huge volume of mobile devices and gadgets carried by the individuals threaten their privacy by identifying their current locations. Along with, most of the intelligent vehicles are equipped with tracking systems [199], which is again a challenge to preserve and publish individual's privacy. To limit the potential of identifying sensitive information about individuals, privacy-preserving measures are very much necessary. Before handing over personal data for analysis to any third party, identity of the individuals should be removed to avoid misuse [200]. In a study, researchers have proposed a mutual cover algorithm to avoid the leakage of personal identity and depth analysis of the data breaches [201].

B. INFRASTRUCTURE SECURITY

Infrastructure security deals with the physical security of the devices, equipments, machines, buildings, vehicles, etc., in smart city environment. Different infrastructure security domains are described below:

1) TRANSPORTATION SECURITY

Transportation amenities in smart cities play a significant role to make the life of the residents convenient. Smart buses and metro trains employ RFID technology to facilitate passenger check-in and check-out. Technological updates, services, and catastrophe management for autonomous transportation system require a particular focus on service security.

2) DEVICE SECURITY

IoT devices physically planted at various sites require a high level of security from external factors. Devices should be compatible with advanced technology, and efficient to work on communication networks. Continuous monitoring of the smart things is necessary to check their functionality, and in case of damage should be replaced on time.

3) SURVEILLANCE SECURITY

In smart cities, surveillance systems are installed for security and monitoring at required places. Intentional or unintentional changes to network settings may cause disabling of networked cameras. Similarly, planned or accidental changes to record settings can cause loss of evidence. Consequently, the security of the surveillance system is very crucial to provide a safe and secure environment to the residents in smart cities.

C. CYBER SECURITY

In a smart city framework, residents are connected in the cyber space using smart devices. Most of the services are provided online to make the life of the users convenient. So, cyber security becomes one of the important aspects to be taken care. Different types of cyber attacks attempted in various smart city applications are discussed below:

1) DISTRIBUTED DENIAL OF SERVICE (DDoS)

DDoS attacks are attempted in smart city applications to disturb the network of connected devices, applications and services. In DDoS, intruder makes repeated requests to capture the online resources which facilitate the realization of the targeted applications. After DDoS, the genuine resource requests are not fulfilled due to lack of resources which disturbs the services.

2) SQL INJECTION

In SQL Injection, the attacker uses some tools to identify vulnerabilities in different smart city services and applications [63]. Malicious HTTP requests are sent to the database, where the injected SQL query attempts to gain credentials for data manipulation, as the database contains sensitive information. The cost of these threats may be categorized on the bases of authorization, authentication, data confidentiality, and data integrity [202]. These attacks are attempted in the smart city domains dealing with sensitive information like healthcare, administration, etc.

3) BRUTE FORCE ATTACK

Brute force attack is cryptographic hack attempted to guess the correct password. The hacker keeps on applying all the combinations unless the true password is found. The longer and complex the password is, the more combinations are to be tried. A brute force attack may take long to conduct, if techniques such as data obfuscation are employed, and are sometimes impossible to perform [203], [204]. Hence, it is very important to keep strong passwords in various smart city applications dealing with highly sensitive data like governance, economy, etc.

4) SESSION HIJACKING

While attempting these attacks, an attacker takes over the web session in the targeted smart city application. Usually hijacked services are paying of bills, checking credit card balance, etc. [205]. A session attacker may perform any act that an authenticated user can. Basically, hijackers make the websites fools by taking into confidence and believing that you are the website. A hijacker can seize an online service and cause the user a great deal of difficulty.

5) DNS ATTACK

In smart city environment, intruders find DNS an exciting method for doing malicious operations, such as network recognition, virus downloads, hijack servers or transfer

of data from the network in various applications [204]. It makes the important services unavailable to the residents/stakeholders. Therefore, DNS traffic must be watched to protect against danger.

6) WiFi SECURITY

WiFi is an essential facility for both residents and visitors. Freely available WiFi services can help to avoid unnecessary expenses [205]. However, the inhabitants connected with public access points must be aware of the security issues associated with data transmission using WiFi.

7) SPYWARE

Spyware can steal and/or damage sensitive information related to various application domains in smart city environment. This information may belong to an individual or any public or privately owned organization. Stolen data may be sold to data companies or individuals. Spyware may capture or steal identity of an individual from the credit card or bank account information.

D. SMART GOVERNANCE SECURITY

Smart city governance must ensure a secure environment to the residents, as well as visitors from all aspects [195]. The proper administration of the various services like education, healthcare, food, etc., is a crucial concern and basic need, as discussed below:

1) SMART EDUCATION SECURITY

In smart cities, higher education organizations are making major investments in digital transformation, embracing new technologies such as WiFi, IoT, location-based services, and on-campus research. However, with the expansion of technology and connection, cyber risks are becoming more and more critical. A smart campus delivers student-focused services as part of the transition and supports business, education, learning, and research [206], [207]. This implies that student's data such as social security numbers, addresses, credit card information, etc., must be safeguarded.

2) SMART HEALTHCARE SECURITY

In smart cities, the notion of smart health is the provision of healthcare services using networks and advanced smart devices. The smart healthcare system offers individuals with health monitoring and accurate diagnosis services [63], [197]. Medical sensors and wearable equipment can be used to check people's health status promptly. The medical data can then be sent to the treatment units for further diagnosis by the doctors. In addition, the complete patient health information may be conveniently accessed from the database, which in turn enhances the potential of early diagnosis of infectious or chronic diseases. Smart governance provides an assurance to keep the medical data safely for future treatment.

3) SMART HOME SECURITY

Smart Home is one of the key components of smart cities, as it is essential in the lives of city folks. Various appliances in the smart homes are equipped with sensing devices [208]. These sensing devices comprise of environmental sensors, movement trackers, security alarms, etc., which provide a platform to ensure secure environment in smart homes.

4) FOOD SECURITY

Administration always keeps a close eye on the quality of the food provided by restaurants and hotels. To keep the city residents healthy, the government always monitors all restaurant services taking care of grievances given by the customers. The government uses smart IT services to track every activity by service providers, and penalize them if not maintaining the quality parameters.

IX. ROAD MAP OF THE CHALLENGES IN SUSTAINABLE SMART CITY DEPLOYMENT

Integration of the advanced technologies in the various constituent systems and subsystems has made the cities smart. It has made the life of the residents convenient by facilitating most of the services online and upgrading many application domains. Although, city services can be sustainable without using computational and communication technologies, being an elemental concept – 'sustainable smart cities', is the need of the hour [209]. Technology equipped smart solutions are the key role players in making the smart cities sustainable [58], [210]. During this survey, it is analyzed that there are many challenges in the sustainable development and deployment of smart city services [211], [212], which are both technical and non-technical, as discussed below:

A. DATA INTEGRATION

In a smart city framework, data are gathered from a variety of smart devices and sensors, which use different formats. Although in the past few years, different technologies are invented and deployed in smart cities to administer this data versatility, still there are challenges to integrate and process the data generated in different applications [213]. When data are mapped to common formats, there are risks associated with the accuracy and completeness [214].

B. SECURITY AND PRIVACY

The integration of the advanced technologies is contributing to enhance the working of different subsystems to improve the QoL of the residents, but also causing the emergence of security and privacy issues. Smart city applications are vulnerable to different types of attacks falling in the categories of spam, collision attacks, sympathy attacks, etc. [215]. Hackers analyze the weakness of AI and ML techniques designed to deliver intelligent services, to breach the security of the applications [216]. In the smart city framework, most of the data is gathered through sensors and smart devices which are prone to cyber attacks. Increasing

the number and versatility of these devices is also a major challenge to scalability of the services delivered in smart city environment.

C. APPLICATION DEVELOPMENT

One major hurdle in the development of smart city applications is the initial cost. Smart city applications and services require the integration of various technologies, hi-tech infrastructure, and other resources. To fulfill these requirements may cause a big financial burden on the administration. Other major cost contributing factors are the technology transfer, mapping of data to common structures, interoperability among the applications, etc. [217]. Huge urban population also causes increased traffic, pollution, economical imbalance, and many other factors to hinder sustainable development.

D. LACK OF RESOURCES

Success of any smart city project primarily depends upon the availability of the needed resources. In some of the countries, the industry is incompetent to deliver the required infrastructure for smart city services. It has been observed that the lack of technology, skilled manpower, and finance are the main reasons causing delay of many smart city projects [218]. Delay of these projects affects the deployment of various services and sustainable development of smart cities.

E. SOCIAL ACCEPTANCE

Social acceptance of any technological revolution is always a challenge. The degree of awareness about the type of smart city services and technology friendliness are the key role players in the acceptance of smart city framework. Awareness of the residents about various smart city services and their functioning is also important to improve the QoL and social well being [218]. Social acceptance of the concept is mandatory for its sustainable development.

F. LACK OF SUITABLE TECHNIQUES FOR TRANSFORMATION

Transformation of a city to a smarter one is a challenging task. It is managed using a systematic approach which needs to be city specific, depending upon the infrastructure, services, governance, and others. Connectivity and communication are the beginning phases of implementation in any smart city project. Suitable techniques and methods are highly required in the process of transformation which is lacking somewhere [218], and impact the sustainable smart city development.

X. SOLUTIONS FOR SUSTAINABILITY CHALLENGES IN SMART CITIES

To administer the different challenges discussed in Section IX, various corrective measures/solutions are proposed. These solutions are either technology-centric, domain-centric, or both. The role played by intelligent ICT in providing quality living and sustainable development in smart city environment is remarkable. AI, ML, IoT, big data,

communication networks, and advanced security frameworks are playing a vital role to provide sustainable energy services to the smart city residents [219]. In [220], authors highlighted the role of IoT and big data in the domain of education by developing an efficient and technology equipped university framework to support environmental sustainability. With the passage of time, the need of sustainability is growing in the governance models too. In [221], authors integrated opinion mining in the processes of policy planning, making, controlling, and evaluation of governance to support comfortable deliberation of sustainable administration services to the residents. Resource availability and management is one of the major challenges in sustainable smart city development. In [223], authors proposed an IoT-based water distribution system. This model was designed to control water wastage and optimize its usage to ensure sustainable smart city services. Land conservation and climate resources are the other major concerns in sustainable smart city development [222]. In [224], authors proposed a fuzzy method-based techniques to analyze the sustainability of mobility in the urban area. This research work is focused on traffic patterns of the Indian cities. In [225], authors discussed smart tourism as the pillar of sustainable living in the state of Mauritius. It is immensely contributing to the economy of the nation. In [226], authors proposed a smart IoT-based air pollution management system. It is used to detect and control the pollution index in the air and aids to provide convenient and sustainable living. Urban planning is the initial point where sustainability should be kept in mind. In [227], a secure big data analytics based smart grid model to manage data collection, storage, load prediction and management, data security and communication, is proposed by the authors to cater sustainable energy services to the residents. Data governance also play a very crucial role to deliver sustainable services in a smart city. In [212], authors impressed upon the need of sustainable planning of the cities to ensure quality services, and better environment to the residents. In [228], authors discussed the solutions provided using efficient and sustainable data governance frame works in the European countries. In [211], authors impressed upon the need of suitable design and development processes to ensure sustainable solutions in a smart city ecosystem. Professional involved in the design and implementation of the services and systems need to be trained with latest technologies and practices for sustainable smart city development.

XI. CONCLUSION AND FUTURE SCOPE

The concept of smart cities emerged as an application of digital innovations to deliver quality services, and allowing the cities to be more efficient. The fundamental aim behind the development of smart cities is to address and solve major urban issues evolving in different functional domains due to huge population and limited resources. Sustainable development is the prime concern in smart city ecosystem. In this paper, authors presented the basics of a smart city, its definition, framework, and the need of sustainable

development. It has been highlighted that the development of smart cities is not one dimensional, but an interdisciplinary and trans-disciplinary approach. Authors also presented the role of CPS in smart cities, and its contribution towards sustainable development. Different smart city applications are also presented in detail. Moving to more technical aspects, the role of various advanced technologies, i.e., AI, big data, blockchain, cloud computing, and IoT for the sustainable development of different functional domains of the smart cities are discussed. Authors highlighted the challenges faced in the deployment of these technologies in different application domains. Advanced and emerging communication and network technologies are discussed as the backbone of smart city framework to provide uninterrupted connectivity among the residents, applications and services. Security issues associated with various applications are categorized as data security, infrastructure security, smart governance security, and cyber security. The domain of smart cities and sustainability of the services are the ongoing research trends for both academia and industry. Authors discussed the challenges faced in sustainable smart city development in detail which lead towards following future research directions:

- More advanced security mechanisms need to be developed to secure smart city data, applications, services, and infrastructure.
- In a smart city environment, data is generated in various application domains usually in different formats. Specialized data integration processes and techniques are highly needed.
- During smart city development, technology transfer is also a big challenge need to be addressed.
- Interoperability issues of the various smart devices, equipment, and applications also need to be handled by developing suitable interfacing methods/techniques.

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