Everything You wanted to Know about Smart Cities

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This article is a single source introduction to the emerging concept of smart cities. It can be used for familiarizing researchers to the vast scope of research possible in this application domain. The smart city is primarily a concept and there is still not a clear and consistent definition of among practitioners and academia. In a simplistic explanation, a smart city is a place where traditional networks and services are made more flexible, efficient, and sustainable with the use of information, digital and telecommunication technologies, to improve its operations for the benefit of its inhabitants. Smart cities are greener, safer, faster and friendlier. The different components of a smart city include smart infrastructure, smart transportation, smart energy, smart healthcare, and smart technology. These components are what makes the cities smart and efficient. Information and communication technology (ICT) are enabling keys for transforming traditional cities to smart cities. The two closely related emerging technology frameworks Internet of Things (IoT) and Big Data (BD) make smart cities efficient and responsive. The technology has matured reasonably to allow smart cities to emerge. However, there is much need in terms of physical infrastructure, renewable energy, ICT, and IoT, and BD to make the majority of cities worldwide smart.

1. Smart City: What is It and Why is it Needed?

What is smart city and why are many people taking about it? In the last several years there has been explosive growth of information and communication technologies (ICTs) due to advancement of hardware and software designs. The use of ICT in cities in various forms for different city activities has led to the increased effectiveness of city operations and these cities have been labeled using many terms such as "cyberville", "digital city", "electronic city", "flexicity", "information city", "telicity", "wired city", and "smart city". Smart city is the largest abstraction among the labels used as it encompasses other labels used for cities. The smart city is a concept and there is still not a clear and consistent definition of the concept among academia and practitioners. In a simplistic explanation, a smart city is a place where traditional networks and services are made more flexible, efficient, and sustainable with the use of information, digital and telecommunication technologies, to improve its operations for the benefit of its inhabitants. In other words, in a smart city, the digital technologies translate into better public services for inhabitants, and for better use of resources while impacting the environment less. One of the formal definitions of the smart city is the following: A city "connecting the physical infrastructure, the information-technology infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city". Another formal and comprehensive definition is the following: "A smart sustainable city is an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operations and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social and environmental aspects". A broad overview of various components needed in a smart city is depicted in Fig. 1. Any combination of various smart components can make cities smart. A city need not have all the components to be labeled as smart. The number of smart components depends on the cost and available technology.
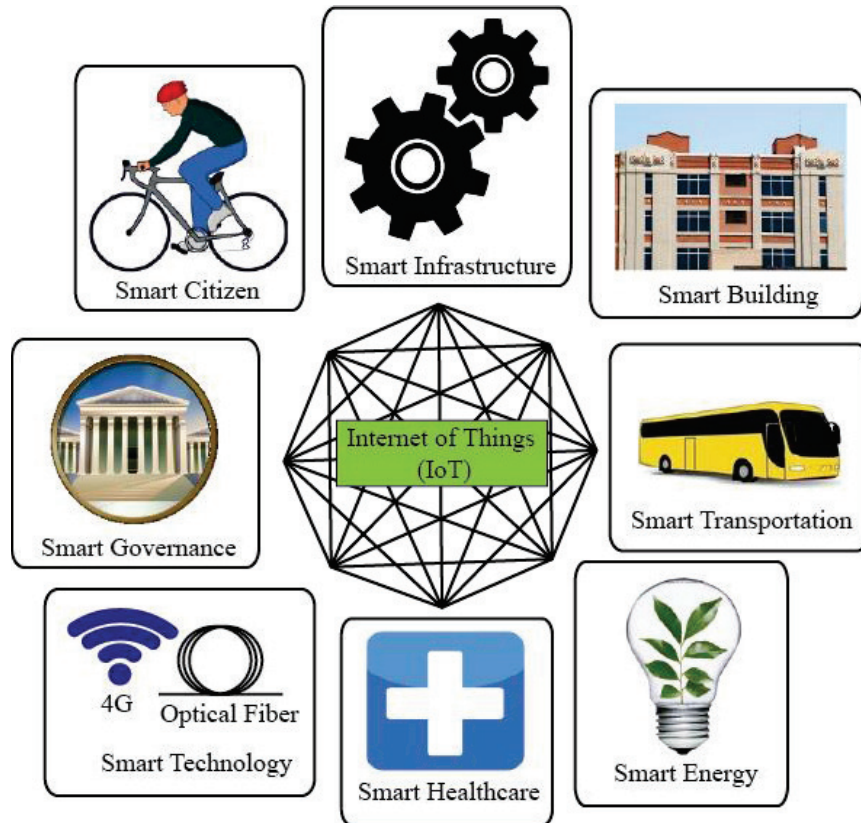
FIGURE 1. A Broad Overview of Smart City Components.

World population has increased significantly in the last decades and so has the expectation of living standards. It is predicted that around 70% of the world population will live in urban areas by the year 2050. At present cities consume 75% of the world's resources and energy which leads to the generation of 80% of greenhouse gases. Thus, in the next few decades there can be severe negative impact on the environment. This makes the concept of smart cities a necessity. The creation of smart cities is a natural strategy to mitigate the problems emerging by rapid urbanization and urban population growth. Smart cities, in spite of the costs associated, once implemented can reduce energy consumption, water consumption, carbon emissions, transportion requirements, and city waste.

Smart cities around the globe are quite diverse in terms of their characteristics, requirements, and components. In general, standards established by organizations such as the International Organization for Standardization (ISO), provide globally understood specifications to drive growth while ensuring quality, efficiency, and safety. Standards can play an important role in the development and construction of the smart city. Standards can also provide requirements for monitoring the technical and functional performance of the smart cities. Standards can also help tackle climate change, address security and transportation issues, while ensuring the quality of water services. Standards take into account various factors such as business practices and resource management, while helping to monitor the smart city's performance and thus reduce its environmental impact. IEEE has been developing standards for smart cities for its different components including smart grids, IoT, eHealth, and intelligent transportation systems (ITS). A specific example of such a standard is ISO 37120 which defines 100 city performance indicators which include 46 core and 54 supporting indicators. Some selected indicators are the following: economy, education, energy, and environment, which can be used by city civic bodies to benchmark their service performance, learn best practices from other cities as well as compare their city against other cities.

2. Smart Cities: Components and Characteristics

Components and characteristics of the smart city are summarized in Fig. 2. There are many components of a smart city and 8 different components have been presented in the figure. The components of a smart cities include the following: smart infrastructure, smart buildings, smart transportation, smart energy, smart healthcare, smart technology, smart governance, smart education, and smart citizens. A brief discussion of these components will be presented in the subsequent sections. Different smart cities have different levels of these smart components, depending on their focus.
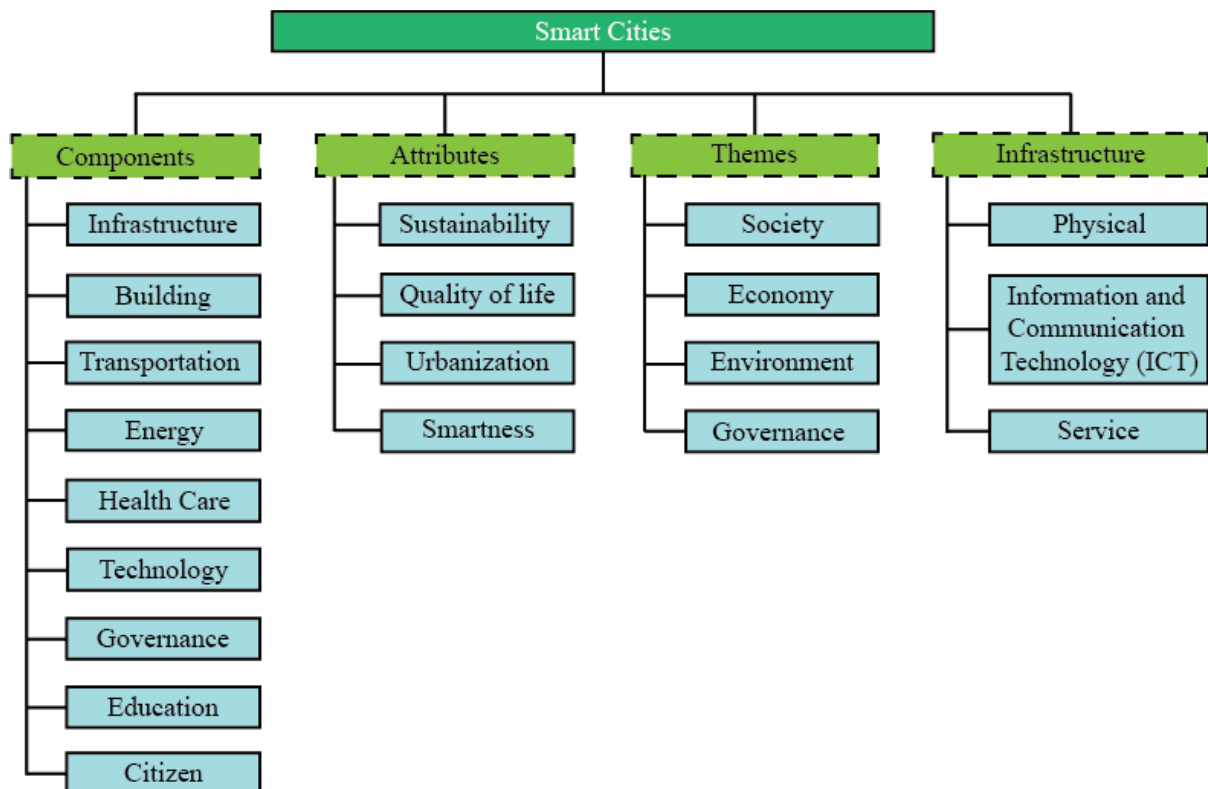

FIGURE 2. Components and Characteristics of Smart Cities.

The various attributes of smart cities include sustainability, quality of life (QoL), urbanization, and smartness. The sustainability of a smart city is related to city infrastructure and governance, energy and climate change, pollution and waste, and social issues, economics and health. The quality of life (QoL) can be measured in terms of the emotional and financial well-being of the citizens. The urbanization aspects of the smart city include multiple aspects and indicators, such as technology, infrastructure, governance, and economics. The smartness of a smart city is conceptualized as the ambition to improve economic, social and environmental standards of the city and its inhabitants. Various commonly quoted aspects of city smartness include smart economy, smart people, smart governance, smart mobility, and smart living.

There are four core themes for a smart city, namely society, economy, environment, and governance. The society theme of a smart city signifies that the city is for its inhabitants or the citizens. The economy theme of a smarty city signifies that the city is able to thrive with continuous job growth and economic growth. The environment theme of a smart city indicates that the city will be able to sustain its

function and remain in operation for current and future generations. The governance theme of a smart city suggests that the city is robust in its ability to administer policies and combining together the other elements.

The infrastructure of the smart city includes physical, information and communication technology (ICT), and services. The physical infrastructure is the real physical or structural entity of the smart city including buildings, roads, railway tracks, power supply lines, and water supply system. The physical infrastructure is typically the non-smart component of the smart cities. The ICT infrastructure is the core smart component of the smart city which glues together all the other components in essentially acting as the nerve center of the smart city. Service infrastructure is based on physical infrastructure and may have some ICT components. Examples of service components include mass rapid transit system and smart grids. The number of city facilities required as a function of city population can be calculated as follows:

$$N_f = N_p \left(\frac{R_p}{Year} \right) \left(\frac{1\,Year}{D\,Days} \right) \left(\frac{1\,Hour}{N_c\,People} \right) \left(\frac{1\,Day}{H\,Hours} \right)$$

where N_f is the number of facilities, N_p is the city population in millions, R_p is the rate per person use in year/week, D is days per year, N_c is the customers per hours, and H is the hours per day.

3. Smart Infrastructure and Building

In a classic sense, the infrastructure of a city is any physical component of the city such as roads, buildings, and bridges that make the city and its inhabitants operate. However, in the context of smart cities, anything physical, electrical, and digital that is the backbone of the smart city can be considered as its infrastructure. There are many examples and a few are: rapid transit system, waste management system, road network, railway network, communication system, traffic light system, street light system, office space, water supply system, gas supply system, power supply system, firefighting system, hospital system, bridges, apartment homes, hotels, digital library, law enforcement, economy system, etc. The smart infrastructure concept is presented in Fig. 3. The backend of the smart infrastructure is the ICT infrastructure which make the physical infrastructure "smart". The ICT infrastructure is fundamental to the construction of smart cities and depends on factors related to its availability and performance. The ICT infrastructure includes communication infrastructure such as fiber optics, Wi-Fi networks, wireless hotspots as well as service-oriented information systems. Smart infrastructure is more efficient, safe, secure, and fault-tolerant as compared to classic infrastructure. The smart infrastructure may have physical infrastructure, sensors, firmware, software, and middleware as its overall components. The "middleware" which is a specific type of software typically plays a crucial role in automation and the quick response of smart infrastructure. Middleware accumulates data and combines them into a common platform for analytics and reporting. The middleware in the process can perform web-based dashboard displays for a visual snapshot of the infrastructure. When experiencing high energy usage, abnormal maintenance costs, and many normal and abnormal situations, the prompt attention of the operation staff is requested. The middleware provides the executives in charge or operation staff numerous information including carbon footprint management and sustainability as well as the big picture of the smart city infrastructure, no matter how many infrastructures, buildings or geographic locations are involved as a whole. The information of the smart infrastructure through the middleware and ICT is available quickly and can be accessed anywhere by the operation staff and management for better decisions that have an immediate impact on the smart city operations. A specific example of smart infrastructure is a smart power grid or, as it simplistically called, a smart grid. A smart grid consists of various energy sources (renewable or conventional), smart meters, operational control mechanisms, load balancing mechanisms, and fault-tolerant mechanisms for efficient and reliable power delivery to the end user from the various energy sources.
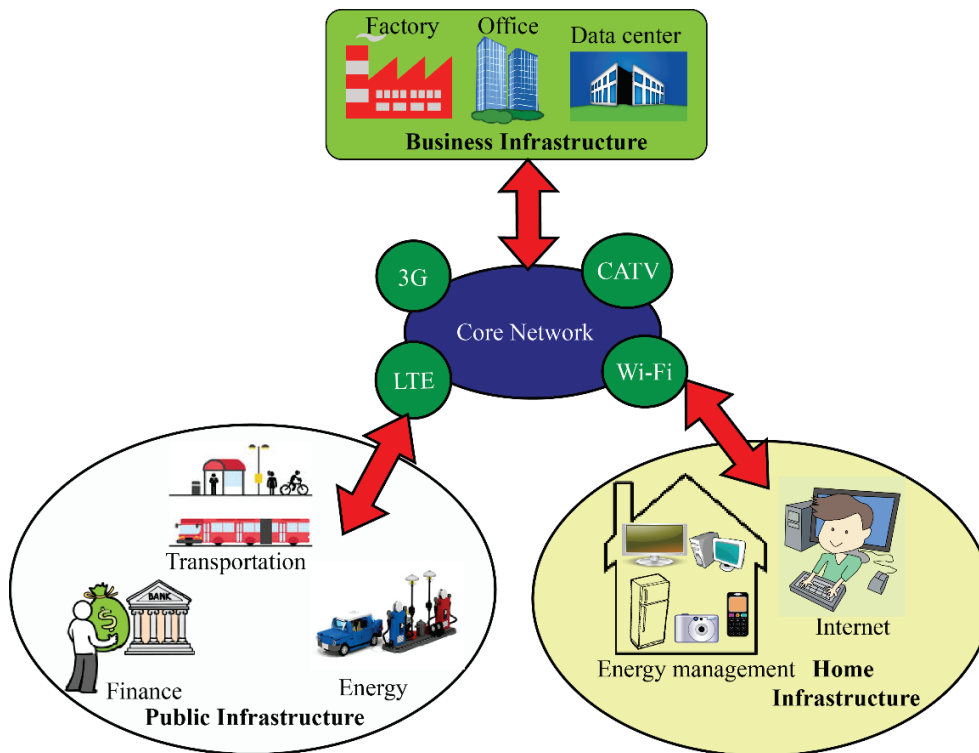
FIGURE 3. Smart Infrastructure Depictions.

Smart buildings can be considered as part of the smart infrastructure or they can be considered as independent components of smart cities. A smart building can have different hardware, software, sensors, and smart appliances, for different automated operations including data network, voice-over-IP (VoIP), video distribution, video surveillance, access control, power management, and lighting control. Smart buildings are different from green buildings. Green buildings are sustainable structures with high energy efficiency, water efficiency, and indoor environmental control with an objective of reducing their carbon footprint and provide optimal energy performance. Smart buildings are a much larger concept than green buildings. Smart buildings can easily connect to other buildings, people and technology, the global environment, and smart power grids. Smart buildings effectively use the knowledge that is available outside their walls and windows. For example, the smart grid can be used by smart buildings. In this scenario, the smart building can easily adapt to its energy demand as well as that of the grid to have effective and low-cost power utilization. Smart buildings can use dynamic electric rates in which a building is charged closer to the actual cost of producing electricity at the instant it is used instead of the average cost over long time periods. The use of the Internet of Things (IoT) provides integrated solutions that can process and analyze large amounts of data that will maximize the operational and energy efficiency of smart buildings. The advantages of the smart building include the following: data driven decision-making for high efficiency and low-cost operations, higher resource utilization, reduced capital and operational cost structure, risk identification and management, and sustainability.

4. Smart Transportation

Traditional transportation systems or facilities such as the railway network, road transport, airline transport, and water transport have existed for a long time. In traditional transport each of these operates independently even in a specific type of transport system, making global usage difficult. Smart transportation also known as the Intelligent Transport Systems (ITS) includes various types of

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communication and navigation systems in vehicles, between vehicles (e.g. car-to-car), and between vehicles and fixed locations (e.g. car-to-infrastructure). ITS also covers the rail, water, and air transport systems, and even their interactions. A broad illustration of the smart transportation is presented in Fig. 4. The smart transportation system has made it possible to construct global airway hubs, intercity railway networks, intelligent road networks, protected cycle routes, protected pedestrian paths, and integrated public transport for safe, rapid, cost effective, and reliable transportation. The use of ICT and real-time data processing has made the smart transportation system possible. The smart transportation system maximizes the utilization of the vehicles used in the system, for example, the number of aircraft that an airline has or the number of trains a railway network has. The smart transportation system allows passengers to easily select different transportation options for low-cost, shortest distance, or fastest routes.

FIGURE 4. Illustration of Smart Transportation.

Specific examples of smart transportation technology including sensors in vehicles for collision avoidance and anti-skidding to increase the safety of the system. A radio frequency identification (RFID) based toll collection is an example of smart transport technology. In the RFID toll collection drivers need not stop at a physical toll booth which typically takes time, blocks the traffic flow, as well as requires manpower for toll collection. Automatic passport control at airports is an emerging technology deployed in smart transportation. In automatic passport control, the passengers can use RFID based passports or electronic passports for fast and reliable entry without the need for manual passport check. Another example of smart transportation is the use of smart apps in mobile phones to hire taxis and even tracking the exact location of the taxi and driver information in the same smart app.
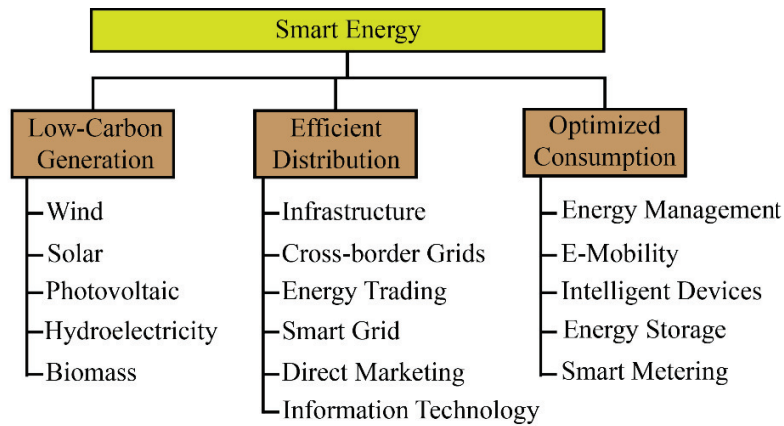
5. Smart Energy

Energy is the property of an object or system which defines its ability to produce work. Energy can be in various forms such as potential energy, kinetic energy, chemical energy, and thermal energy. Energy sources are also quite diverse including solar, fossil fuels, gas, electricity, and battery. Energy can be neither created nor destroyed but can be transformed from one form to another. In the last several years, in addition to traditional energy forms, many other terms are associated with it including clean energy, green energy, sustainable energy, renewable energy, and smart energy. The fear that energy sources available for human consumption will be depleted has been driving these new energy related terms. Clean energy or green energy suggests that the energy consumption has very minimal negative impact on the environment. For

example, solar energy or wind energy are forms of green energy sources. Sustainable energy and renewable energy are energy sources which cannot be consumed within a few generations and can be regenerated faster than they can be consumed. However, there can be some differences between sustainable energy and renewable energy: sustainable energy sources are ones not created by human beings, whereas renewable sources are created by human beings. One example of renewable energy is bio-gas which requires the growth, consumption and disposal of organic materials to generate it. Another related term is zero energy system or zero-energy buildings in which the energy consumed and energy generated are the same quantity and hence the net consumption in these structures can be considered as zero. What is smart energy? Smart energy is a much broader concept that any of the above such as traditional energy or clean energy, etc. Smart is a concept which can be viewed as an "Internet of Energy" model. This model is based on one or more principles of smart power generation, smart power grids, smart storage, and smart consumption. In essence any traditional energy, clean energy, green energy, sustainable energy, and renewable energy along with the information and communication technology (ICT) makes smart energy. The various different components of smart energy are presented in Fig. 5(a). An illustration of a smart energy system is presented in Fig. 5(b).

The smart energy system consists of the intelligent integration of decentralized sustainable energy sources, efficient distribution, and optimized power consumption. Smart energy thus consists of three independent building blocks that must be stitched together and effectively communicate with each other to form a unified smart energy system. Low-carbon generation, also known as a green energy, photo-voltaic, solar thermal, bio-gas, and wind energy can be an important part of a smart energy system. Efficient distribution in the smart energy system is made possible by the use of smart infrastructure, smart grid, smart meters as well as an appropriate level of utilization of the information and communication technology (ICT). The core of a smart energy system is the information infrastructure which is responsible for collecting the energy consumption information as well as sharing the provider rate information. The ICT can be used to control the operations with appropriate level of energy consumption for smart appliances like dishwashers and water heaters. ICT is also useful for transactions for plug-in electric vehicles (PEVs) and heating, ventilation, and air conditioning (HVAC). ICT can be effectively used to purchase energy from various diverse sources such as solar panels systems, wind turbine systems, and other possible energy sources. Optimized consumption of the system is the 3rd key component of the smart energy system. The effective use of efficient energy storage, smart metering, and effective energy management can be keys for optimizing energy consumption in a smart energy system.

The backbone of a smart energy system is the smart energy grid or smart grid. In a formal definition, the smart grid efficiently integrates the actions and behaviors of all connected users such as: (1) consumers, (2) generators, and (3) users who are both consumers and generators. Smart grids ensure efficient, economical, and sustainable energy systems with low levels of loss, higher quality supply, safety of system and users, security of the supply, and faculty-tolerance of the system. Smart grid makes it possible to integrate diverse sources of energy available, from fossil fuel based thermal energy to green photo-voltaic energy, and wind energy. The future smart grids will be much more complex than the current generation. For example, a day may come when every user also generates solar energy, bio-fuel energy, and even wind energy. A smart grid will effectively synchronize this energy from diverse sources and provides electricity at specified voltage and frequency without any fluctuations. The use of ICT plays a key role in a smart grid for the following: (1) to support demand-response management of energy usage, (2) to dispatch power generation for solar panels and wind turbines, (3) to facilitate location-independent, point-of-sale transactional services for PEVs, and (4) enhancing consumer relationships. Smart energy metering is an important component of the smart grid. The smart meter records consumption of electric energy in certain time intervals and communicates that information to the utility for monitoring and billing. This facilitates accurate and reliable reading of utilization without human reading or recording involvement. A smart battery or intelligent battery which can be made from lithium ion or fuel cells can be effective for energy storage and efficient delivery while having longer life.

(a) Components of Smart Energy
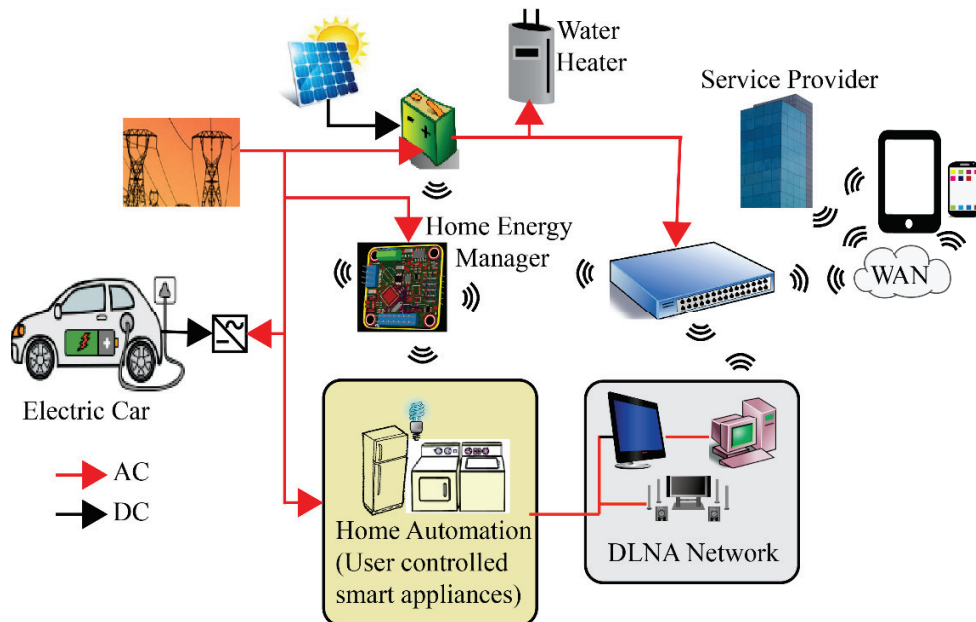
(b) Illustration of a Smart Energy System

FIGURE 5. Smart Energy and Smart Energy System.

6. Smart Healthcare

Due to the rapid growth of population, traditional healthcare is overwhelmed. There are not enough medical practitioners to meet the need of the citizens. Many times hospitals make mistakes in handling infectious diseases. In many occasions patients receive the wrong medication. In many remote places in the planet receiving adequate healthcare is still a distant dream. Thus, with limited resources and ever increasing demand, traditional healthcare needs to be intelligent, efficient, and sustainable; that is where smart healthcare comes in. Smart healthcare can be conceptualized as a combination of various entities including

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traditional healthcare, smart biosensors, wearable devices, information and communication technology (ICTs), and smart ambulance systems. The idea of smart healthcare is presented in Fig. 6. The various components of smart healthcare include emerging on-body sensors, smart hospitals, and smart emergency response. In smart hospitals, various mechanisms including ICTs, cloud computing, smart phone apps, and advanced data analysis techniques, are used for their operation. The patient data can be made available in real-time at various offices in a smart hospital or even various smart hospitals in different cities or the same city. Medical technicians, nurses, and doctors can have access to the test data without loss of any time in transferring the same information physically from one office to another. Similarly, different doctors can see the information to make judgments on a patient's condition. Thus real-time decisions on patient health conditions and corresponding medication can be made possible.
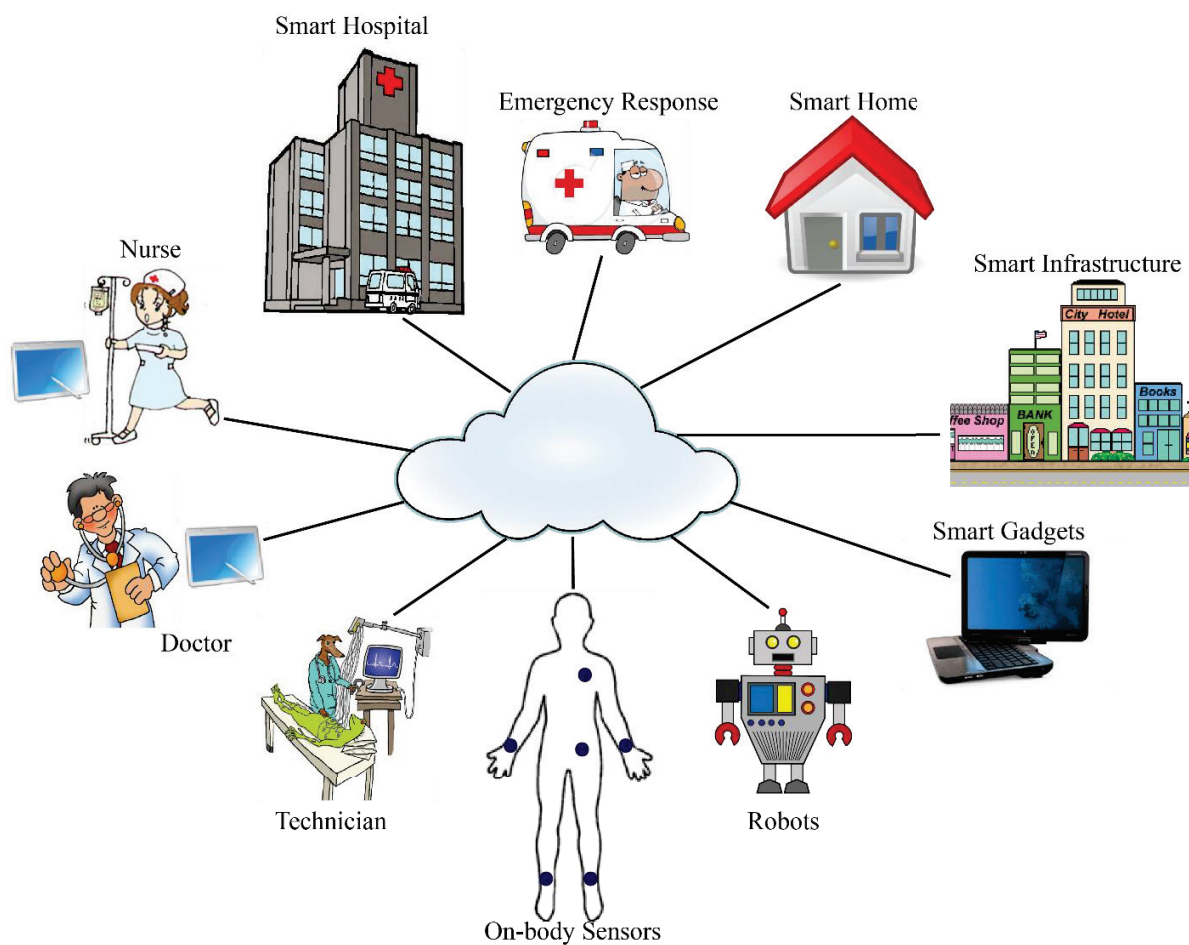

FIGURE 6. The Idea of Smart Healthcare.

Telemedicine can be considered as a specific example of smart healthcare. Telemedicine can also be considered as a subset of smart healthcare. Telemedicine uses information and communication technologies (ICTs) for providing clinical health care at a long distance or in remote locations. This approach is particularly useful for remote places in which healthcare services are not easily accessible; telemedicine eliminates the distance barriers and improves access to medical services in such remote locations for distant rural communities. Telemedicine is envisioned to provide critical care in emergency situations and can save lives in such critical situations. Another example in which smart healthcare can have significant impact is in assisted living for elders. In assisted living, seniors have as much independence as possible in their daily

activities with minimal need of skilled nursing care. Smart healthcare can further add to the quality of life in assisted living for seniors where a doctor, a nurse, a health report are easily available for them round the clock.

7. Smart Technology

Smart technology is key for the design, implementation, and operation of smart cities. A variety of selected technologies used in smart cities is presented in Fig. 7. A diverse variety of components including infrastructure, buildings, physical structures, electrical infrastructure, electronics, communication infrastructure, information technology infrastructure, and software, make the smart cities happen. A design and operation challenge is how to have a good mix of the smart technologies so that the smart cities are not over smart, rather sufficiently smart to be sustainable for years and years. Thus, it is important that the cost of deployment of such smart technology is not a serious overhead for tax revenue of the citizens of the smart cities. However, as science and technology make progress, smart technology can become cheaper and smart cities may become an economically viable option.
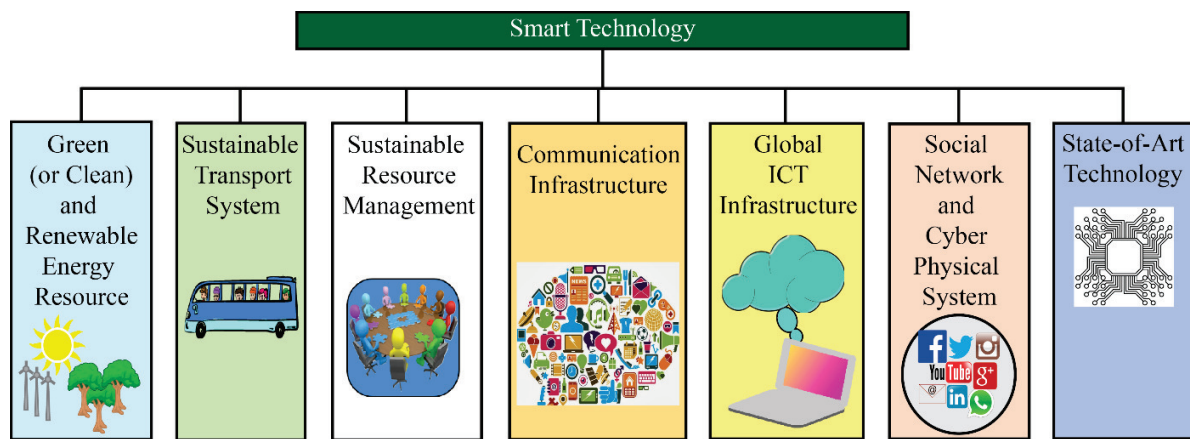

FIGURE 7. Selected Possibilities of Smart Technologies.

Green or renewable energy resources such as solar power and wind power as discussed in a previous Section are an example of smart technology which is key for smart cities. Green buildings and green neighborhood development communities are also important for smart cities. Green buildings and hence the corresponding communities using them are categorized by rigorous standards programs like Leadership in Energy & Environmental Design (LEED) in the US and Building Research Establishment Environmental Assessment Methodology (BREEAM) in the UK. The LEED program in the USA is a green building certification program that identifies the best-in-class building strategies and practices. In order to achieve the LEED certification, the building projects must satisfy prerequisites and earn scores to obtain different levels of certification. For example, LEED v4 which is the newest version certification includes important aspects like materials of the building, indoor environmental quality, smart grid, and water efficiency. Similarly, BREEAM includes several categories for the assessment, including management, energy, pollution, materials, waste, water usage, and healthcare.

A sustainable transport system is a key technology for smart cities. Sustainable and smart transport systems, for example mass rapid transit systems (MRTS), can transport large numbers of people from one destination to another. This can reduce traffic congestion and is helpful in reducing greenhouse emissions which have a negative impact on global warming. Smart communication technology and ICT are important technologies which include fiber optics to home, citywide Wi-Fi, near field communication (NFC), and Bluetooth. Citywide Wi-Fi can make use of basic services such as calling a taxi easier. NFC can

revolutionize the way credit cards are used; may be the day will come where we will have a cash less society. Cyber physical systems (CPS) which are integrations of computation, networking, and physical entities just like the internet of things (IoT) are a key to make physical entities smart. Social networks and short-message services (SMS) have created communications mechanisms to efficiently avail utilities in smart cities. A variety of state-of-the-art technologies can be used to make the cities smart. The above discussed technologies like Wi-Fi, and NFC can be considered as part of this; however, there are many other forms of smart technology. A specific example of state-of-the-art technology are smart meters that can measure and record consumption of various utilities such as electricity, gas or water and communicate that information for monitoring and billing to central facilities. Another state-of-the-art technology is electronic cards or smart cards which contain a unique encrypted identifier that allows the owner to log in to a range of services without setting up multiple accounts. A network of secure digital cameras can be an effective solution for secure and copyrighted image or video communication in the IoT for use in smart health care and smart transport.

8. Smart City Design: Challenges and Opportunities

The challenges for building smart cities are quite diverse and complex. A few include cost, efficiency, sustainability, communication, safety, and security, as depicted in Fig. 8. These design challenges are governed by various factors including the natural environment, government policy, social communities, and economy. Cost is the most important factor of the smart city design. The cost includes design cost and operation cost. The design cost is a onetime cost of the smart cities. Operation cost is that cost that is required to maintain the smart city. Design cost needs to be small to make a smart city realization possible. At the same time small operation cost will make it easier for cities to operate on a long run with minimal burden on the city budget. Cost optimization over the complete system lifecycle can be a challenging problem. Operation efficiency of the smart cities is an important challenge: higher efficiency can reduce the operational cost and improve sustainability of the smart city. Cutting down carbon emissions and city waste is needed to enhance sustainability and efficiency, and reduce operation cost. Smart cities need to cope up with population growth while ensuring long-term sustainability with optimized operation cost. Smart cities need to be resilient to disasters and failures. Disasters can come from nature. Failures can originate for many reasons in the system such as a failure in ICT, or power failure. Natural disasters also can lead to failure of various components of smart cities. Any smart city design needs to take these disasters and failures into consideration so that the smart cities can quickly recover from such situations within minimal time. The design and operation cost of the smart cities will be affected by these challenges. Smart cities are made possible due to the effective use of many smart components including ICT, sensors, and IoT and will need to process and store large volumes of data. Security of the information and infrastructure is an important design challenge. Above all, public safety is a critical design challenge for smart cities as the safety of the inhabitants is of paramount importance, which can also increase design and operation budgets.

9. The Internet of Things (IoT) in Smart Cities

The core of smart city implementation is the Internet of Things (IoT). In other words, the IoT is the technical backbone of smart cities, as depicted in Fig. 9. The smart cities need to have three key features: intelligence, interconnection, and instrumentation which the IoT can provide. It can be said that the use of the IoT can make the smart cities feasible. The use of smart phones, smart meters, smart sensors, and radio-frequency identification (RFID) in essence forms the IoT framework in the smart cities. The IoT framework consists of various components including electronics, sensors, networks, firmware, and software. IoT is the network of interconnected physical objects (called "things") including computers, smart phones, sensors, actuators, wearable devices, homes, buildings, structures, vehicles, and energy systems. The IoT ensures the communication of many variety types of systems and applications for providing increasingly smart, reliable and secure services. A large variety of sensors including RFID, IR, and GPS, connect the buildings, infrastructure, transport, networks and utilities through ICT. Various tasks such as for information exchange

and communications, intelligent recognition, location determination, tracking, monitoring, pollution control, and identity management can be performed by the IoT framework. A related term "Cyber Physical System (CPS)" can be brought to the discussion in relation to the IoT. It is difficult to distinguish the two terms CPS and IoT based on the available literature. CPS is a much larger entity than the IoT, in other words, IoT is a network/communication subset of CPS. It is the implementation of IoT in a physical system that leads to a CPS.
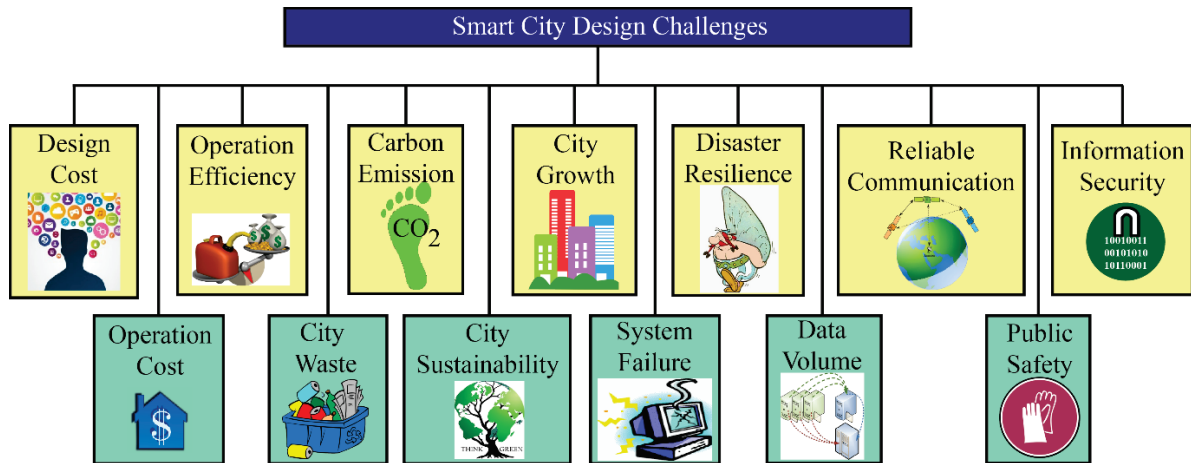

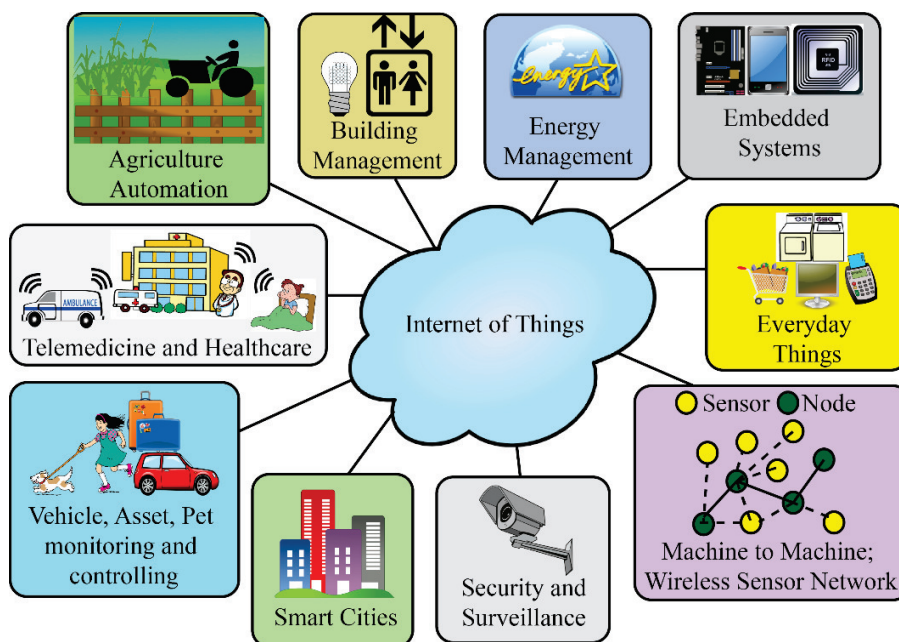FIGURE 8. Selected Challenges in Smart City Design.

FIGURE 9. Internet of Things (IoT) in Smart Cities.

The IoT can be conceptualized as a configurable dynamic global network of networks. There are four main components of the IoT: (1) The Thing, (2) The local area network (LAN), (3) The Internet, and (4) The cloud. The Thing is a sensor, embedded computing device or embedded system which can transmit and

receive information over a network in order to control another device or interact with a user. An example of the Thing is a temperature sensor, a microcontroller or a microprocessor-based device. On the other hand, microwave, sprinkler, house, washing machine, or building do not come under the definition of "Thing". However, the IoT along with these physical entities such as buildings can make a Cyber Physical System (CPS). The "Thing" may perform the following: (1) identification and storage of information, (2) collect information, (3) understand commands, (4) transmit and receive messages, (5) sense, and (6) actuate. The IoT can be used to build smart transportation, smart health care, and energy management in smart cities.

10. Big Data in Smart Cities

In general, Big Data refers to a collection of large and complex data sets such that it is difficult to process using regular database management tools or traditional data processing applications. The Internet of Things (IoT), Big Data, and Smart cities are strongly inter-related as one needs the other two. The urban data which are tagged in space and time and are generated in the smart cities can be Big Data. The Big Data in the smart cities may be generated from a large collection of sensors, databases, emails, websites, and social media as presented in Fig. 10. It is estimated that the proliferation of sensors, social networks, web pages, image and video applications, and mobile devices are generating more than 2.5 quintillion bytes per day. The challenges of Big Data are multifold including visualization, mining, analysis, capture, storage, search, and sharing. Big Data requires new approaches of processing to enable enhanced decision making, insight discovery and process optimization. Sophisticated data analysis mechanisms are necessary to search and extract valuable patterns and knowledge from the Big Data of the IoT and smart cities.
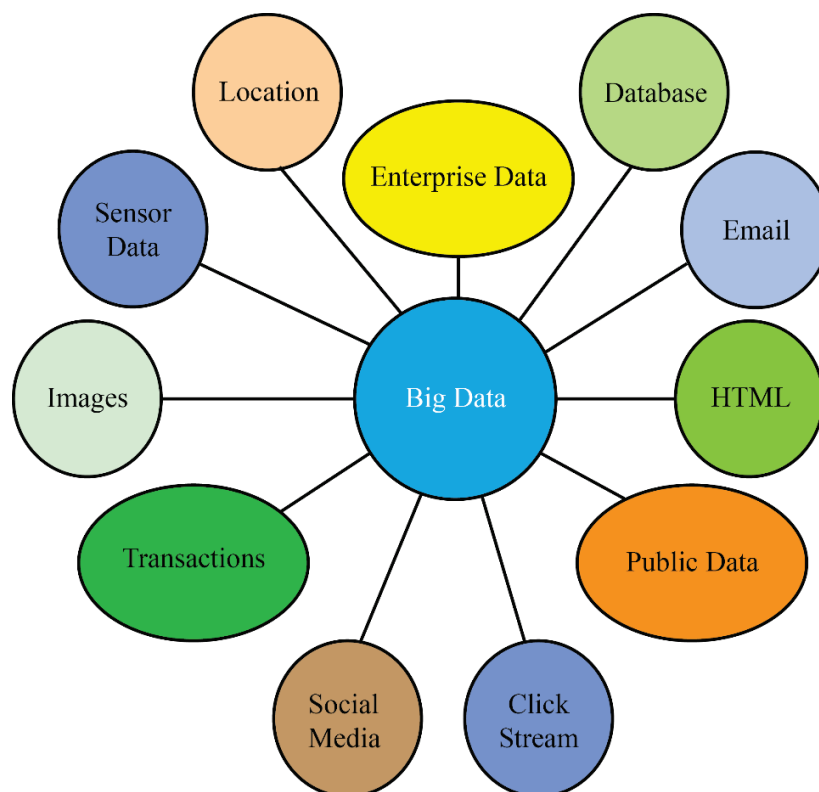

FIGURE 10. Big Data in Smart Cities.

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Big Data has several important characteristics including the following: (1) complexity, (2) volume, (3) variety, (4) variability, (5) veracity. At the abstraction level Big Data can be of 3 types such as enterprise data, public data, and transactions as presented in Fig. 10. Examples of Big Data include atmospheric data, call detail records, genomic data, e-commerce data, Internet search indexing, medical records, military surveillance, photography archives, RFID data, sensor network data, social network data, video archives, and web logs. However, storing a large amount of data may be cheap due to cheaper storage available at present. The stored Big Data can then me mined to retrieved valuable information when needed. The Big Data must be processed with advanced analytics and algorithmic methods and tools to retrieve the meaningful information.

11. Conclusions

In a big picture, a city is a system of systems with a unique history and set in a specific social and environmental context. For a city to prosper, all the key city systems need to work together, by utilizing all of their resources to overcome the challenges the city faces. The "smartness" of a city describes its ability to bring together all its resources, to effectively operate with maximum possible efficiency to fulfil the purposes it has set itself. The smart city is a concept and a variety of definitions exist among academia and practitioners. A smart city can have one or more smart components, including smart transportation, smart grid, smart health care, and smart governance. The Internet of Things (IoT), cyber physical systems (CPS), and Big Data are key technologies in the context of information and communication technology (ICT) critical for the implementation of smart cities. Smart cities with minimal implementation and operation cost are the keys for long-term sustainability. There are several smart cities with some form of smart components operating at present at various parts of the globe. The need for smart cities is increasing day by day with the increase of population as earthly resources are limited.

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