

Smart Cities

**Matthew N. O. Sadiku^{1*}, Tolulope J. Ashaolu², Abayomi Ajayi-Majebi,³
and Sarhan M. Musa¹**

¹Roy G. Perry College of Engineering, Prairie View A&M University, Prairie View, TX, USA

²College of Food Science, Southwest University, Beibei, Chongqing, P.R. China

³Department of Manufacturing Engineering, Central State University, Wilberforce, OH, USA

*Corresponding author details: Professor Matthew N. O. Sadiku; sadiku@ieee.org

ABSTRACT

In this article, smart cities are characterized with factors like their people, transportation, technology, buildings, economy, environment, parking, and governance. The measures and future outlooks of smart cities are also described whilst not undermining both benefits and challenges that are associated with smart cities. Proponents of smart cities must select the transformation strategy that helps them realize their ambition.

Keywords: smart city; smart economy; smart transportation; smart parking; smart people; smart environment; smart governance; smart home; smart technology

INTRODUCTION

Cities, megacities play a major role in economic and social aspects of life worldwide. They are consumers of resources and have a huge impact on the environment [1]. The majority of world's population resides in cities. According to the United Nations, 2008 marked the year when more than 50 percent of people (3.3 billion) lived in cities [2]. Cities are being digitally transformed to improve environmental, financial, and social aspects of urban life.

As a matter of duty, every city needs to provide their citizens with housing, food, water, energy, jobs, health, education, transport, security, etc. Cities' services and infrastructures are being stretched to their limits to support the population growth. Modern cities are monstrous communities, with millions of residents. They are the economic engines of the modern world because they generate economic opportunities. Cities bring individuals together and foster interchange of information by people of different cultures and skills. They collaborate, compete, and evolve together with other cities. As people change cities, cities change them [3].

Cities provide opportunities to its citizen for jobs, economic development, better living standard. These opportunities cause migration of people from villages to cities.

Cities are under pressure in both developed and developing nations to get smarter by addressing large-scale urbanization challenges and find ways for creating livable, competitive, and self-reliant cities [4]. The need is met by the deployment of smart city technologies. Smart cities are an emerging phenomenon, aiming at using digital technology to implement better living conditions.

The final goal of a smart city is to improve the quality of life for the residents.

This chapter presents a brief overview of the concept of the smart city. It begins by discussing the characteristics of smart cities. It covers the basic enabling technologies. It presents some examples of smart cities and the future of smart cities. It addresses some benefits and challenges of smart cities. The last section concludes with comments.

CHARACTERISTICS OF SMART CITIES

The concept of smart city emerges as a major response to the rapid urbanization and socio-economic challenges faced by cities worldwide. Smart city is a relatively new concept, with several definitions. The word "smart" can be used to describe any device that can process information and can communicate with something. The term "smart cities" is a fuzzy concept and there is not a one-size-fits-all definition of the concept. The term has gained traction across sectors and has pervaded the fields of sustainability, urban planning, architecture, engineering, and computer science. The Institute of Electrical and Electronics Engineers (IEEE) defines a smart city as a city that brings together technology, government, and citizens to enable the following characteristics: smart economy, smart mobility, smart environment, smart people, smart living, and smart governance [5].

A smart city is a high-tech urban area that connects people, information and technologies in order to increase life quality. It integrates information and communication technology (ICT) in a secure manner so as to manage the city's assets, increase operational efficiency, share information with the public, and improve citizen welfare. ICT is the key technology that weaves digital intelligence into cities' fabric. The main motivation for using ICT is the desire to eradicate human error. Smart cities are those communities that pursue sustainable economic development through investments in human and social capital and manage natural resources through participatory policies.

Characteristics that may be used to determine a city's smartness include [6]:

- A technology-based infrastructure, which includes a critical mass of smartphones and sensors connected by high-speed communication networks and ICT
- Environmental initiatives, e.g. green rooftops towards clean and green environment
- A functioning public transportation system
- Citizen engagement, humans living and working in the city and utilizing its resources
- Open government and citizen-centric governance, bridging gaps between citizen and administration

A smart city uses networking and computing technologies to create efficiencies, improve sustainability, create economic development, and enhance quality of life for those living and working in the city. It connects various items such as street lighting, smart buildings/homes, smart factories, smart hospitals, smart mobility, urban manufacturing, and urban farming [7]. It monitors the conditions and integrates critical infrastructures such as bridges, tunnels, roads, subways, airports, seaports, and buildings. Components of a smart city include smart people, smart governance, smart homes, smart infrastructure, smart technology, smart campus, smart economy, smart water, smart living, smart factory, smart health, smart parking, smart shopping, smart transportation, and smart environment [2]. Some of these are briefly explained as follows [6,8, 9].

• **Smart People**

Smart city values its smart citizens because the city residents are the most valuable resource of the city. The initiatives should create an urban environment that yields a high quality of life for its residents. The attitude of city residents towards smart city technologies will play a role in technology acceptance. The concept of smart people embraces various factors like affinity to lifelong learning, social and ethnic plurality, flexibility, creativity, open-mindedness, and active participation in public life.

• **Smart Technology**

This is key for the design, implementation, and operation of smart cities. A smart city relies heavily on a collection of smart computing technologies applied to critical infrastructure components and services. These technologies help cities sustain growth and improve efficiency for both citizen welfare and government. They can also deliver a better quality of life.

• **Smart Buildings/Homes**

These are part of a smart city project. Buildings consume a lot of materials, energy, and water. They are responsible for a wide range of impacts on human health and the environment. Attaching sensors to buildings can detect wear and tear and monitor the structural health of buildings. Appliances such as intelligent fridges or smart home security applications create opportunities for more efficient living.

• **Smart Transportation**

This ensures public transportation meets user demand. Smart-mobility applications have the potential to cut commuting time. The role of the smart mobility is to connect all the city's resources: people, goods, and information. The evolution of autonomous and electric vehicles has an impact on transportation. Figure 1 illustrates smart transportation [10].

• **Smart Parking**

Parking is an expensive resource in almost any major city in the world. Smart parking helps drivers find available parking spaces without prolonged circling of crowded city blocks.

• **Smart Economy**

This refers to e-business and e-commerce, and to economic opportunities. It is concerned about competitiveness and economic growth resulting from innovation, productivity, entrepreneurship, and a flexible labor market.

• **Smart Environment**

This deals with the smart utilization of energy and natural resources. It encompasses smart energy as well as renewable energy sources, water, urban services (waste management, drainage systems, public lighting). The smart city concept implies that urban environments have become smarter.

• **Smart Governance**

Many cities have employed ICTs to improve their governance. This ICT-based governance is known as smart governance. This is concerned with using ICT to improve democratic processes and public services (e-government). It aims at utilizing ICT-based solutions to facilitate political participation of citizens in decision-making.

Some of these components are illustrated in Figure 2 [11].

FUNDAMENTAL TECHNOLOGIES

The intelligent city has a wide range of electronic and digital technologies that enable its devices to communicate. Two closely related technologies, the Internet of Things (IoT) and big data (BD), enable the transformation of traditional cities into smart cities [12]. Smart cities have been equipped with heterogeneous electronic devices based on the Internet of things (IoT), which is a worldwide network of physical objects using the Internet as a communication network [13]. As shown in Figure 3, the IoT is the technical backbone of smart cities [14]. The IoT is the network of interconnected devices (called things) including computers, smartphones, sensors, buildings, structures, vehicles, actuators, and wearable devices. It has four components: the things, the local area network, the Internet, and the cloud. Sensors play an important role to make cities better, safer, efficient and sustainable.

To provide all the necessary services to the residents of smart cities, the IoT technology generates big data. Most smart city applications, such as transportation systems, energy management, water utility, waste management, healthcare systems, and surveillance (with cameras) systems, generate big data [11].

The large quantity of data generated by thousands of sensors and devices in a smart city creates a big data. The BD refers to a group of large data sets that would be hard to process using traditional data processing. It is a high-volume, high-velocity, and high-variety information that requires special information processing tools [15]. Gigabit networks will allow smart cities to collect and analyze big data.

Other smart city technologies include artificial intelligence (AI), cloud computing, edge computing, dashboards, firewall, machine learning, SCADA systems, and blockchain. For example, blockchain technologies promise to help in this dilemma by improving cybersecurity as well as user's privacy. Blockchain can contribute to reducing these security gaps. It is a platform on which the massive data derived from smart cities can be safely stored and accessed by those who are authorized to access it.

MEASURES OF PERFORMANCE

Measuring the performance of a city as a smart city is an uphill task. A measurement system, identifying six layers and levels of a smart city, is presented as follows [16].

Layer 0: The City Layer. Smart cities must start with the “city” not the “smart.” This layer conveys the traditional components present in every city.

Layer 1: The Green City Layer. This is inspired from new urbanization theories raised by LEED initiatives.

Layer 2: The Interconnection Layer. This is integral to the smart city concept referring not only to “infrastructural green islands” but also to city-wide diffusion of green economies.

Layer 3: The Instrumentation Layer. This comprises of real-time connections outlets such as radiofrequency transmitters, traffic signals, streets, smart meters, infrastructure sensors, and traffic sensors.

Layer 4: The Open Integration Layer. Smart cities applications should be able to intercommunicate, and share among others data, content, and services.

Layer 5: The Application Layer. Cities are being empowered technologically, as the core systems on which they are based become interconnected.

Layer 6: The Innovation Layer. Smart cities create a fertile innovation environment for new business opportunities. Other measures of smartness of smart cities can be found in [16].

EXAMPLES OF SMART CITIES

Many cities have started transformational projects called smart city initiatives to better serve citizens and to improve their quality of life. Several initiatives all over the world have been launched to transform towns or cities from scratch to smart cities. For example, India decided to set 100 smart cities in May 2014. South Korea initiated 47 U-City (Ubiquitous City) projects in May 2013.

So far, no city has fully become a smart city. However, several cities are actively pursuing smart city strategy. A few of them stand out as the furthest ahead in development. These cities include:

- Chicago
- Philadelphia
- San Francisco
- New York City
- Singapore
- Amsterdam
- Paris, France
- Ottawa, Canada
- Toronto, Canada
- London, UK
- Manchester, UK
- Vienna, Austria
- Madrid, Spain
- Barcelona, Spain
- Tokyo, Japan
- Reykjavik, Iceland
- Melbourne, Australia
- New Delhi, India
- Seoul, South Korea
- Dubai, United Arab Emirates
- Hong Kong, China
- Beijing, China

The smartest city in the world is Singapore. People who live or visit there often have the sentimental feeling as if they are living in the future.

FUTURE OF SMART CITIES

The term “smart city” was first used in the 1990s. Since then, three different generations of smart cities have emerged [6]: (1) Smart City 1.0 was led by technology providers; (2) Smart City 2.0 was led by the cities; (3) Smart City 3.0, neither the technology providers nor the city leaders take control; instead, a citizen co-creation model is being embraced. Big companies such as IBM, CISCO, Microsoft, Philip, and Oracle are generalizing their products as they see markets in cities representing the next wave of product development in the globally distributed world [17].

Cities are going smart and are constantly in flux. They are the future of humankind. As cities continue to change over time, so our solutions also need to change and adapt over time. IBM’s high-profile campaign on smart cities also goes some way to acknowledge this pressure for cities to become smarter. The smartness of a city is demonstrated by how well it uses data and technology. As cities get smarter, they are becoming more livable and responsive. Smart city applications must be aligned with where a city and its citizens want to go [18]. By necessity, the cities of the future should strive to be greener. A green city is a city that is focused on sustainability. The major benefits of the green cities include oxygenation and purification of urban air, mitigation of the heat island phenomenon, the increasing of biodiversity by creating semi-natural habitats, the use of bio-architecture to connect man and nature through the medium of landscape improvements, and the psychological impact on residents [19].

We must be deliberate in the development of smart cities and ensure that the city of the future is a city for everyone. Visionary leadership is critical in avoiding some pitfalls, as well as developing mechanisms for shared governance. Successful deployment of smart city technologies depends on the quality of the decisions that are made and the way these decisions are executed.

BENEFITS

Smart cities are essentially tech-savvy towns that utilize digital technologies to do their business and create efficient and livable environment. There are many benefits that result from transforming a city into a smart one. It is argued that smart cities promise sustainable development and a high quality of life for the residents. Smart cities act as magnets for highly educated individuals and skilled workforces. They enable social, environmental, economic, and cultural development. They are an exciting place to live and the breeding ground for new ideas.

Experts claim that smart cities could be efficient and more enjoyable places to live. The smart city initiatives have lofty goals of improving governance and enhancing quality of life for citizens. Smart cities offer untold benefits for government and citizens—service provision, quality of life, and security. These benefits include integrated transport system, tourism, health, educational facilities, smart healthcare, smart energy, smart homes, crime prevention, smart infrastructure, safety and security, disaster management, and waste management.

CHALLENGES

Current efforts towards creating smart cities face some challenges. Common challenges include extreme weather conditions, growing food shortages, competition for resources, increasing rural-to-urban migration, increased congestion, ageing populations, and increased costs of

public services [20]. Although the rapid advancements in ICT help in the digitalization of cities, they also create new challenges due to the increasing complexity and dynamics in the smart city.

Building smart cities has its potential barriers and challenges [21]. Smart cities around the world are diverse in their characteristics. In order to realize the full benefits of IoT, IoT requires a standard platform and "battle-tested" framework for the next generation of smart cities. International standardization plays a crucial role in ensuring interoperability among services and devices. Standards (such as established by ISO and IEEE) can play a crucial role in the development of smart cities. We must ensure that the information is secure and the people are secure. Since networks are believed to be the least secure parts of the system, cities must ensure that the networks are safe before embarking on smart city initiatives. In addition to these challenges, there will be the impact on cities of global climate change.

CONCLUSION

Cities are regarded as the key elements for the future and smart cities are considered the wave of the future. The urgent need of making the city a more suitable, efficient, sustainable, and safe place is triggering many initiatives around the world. Cities want to be smart and are implementing smart cities initiatives. The main goal of a smart city is to improve the lifestyles of its residents by providing them a sustainable environment at affordable costs. This is what democratization of technology is all about.

Smart cities are being pushed by big high-tech companies. Local governments now face the need to transform themselves into smart cities. They must select the transformation strategy that helps them realize their ambition. Making cities smarter will continue to be important.

Universities have become natural testing grounds for smart city solutions. University laboratories provide facilities to implement some smart city technologies in a manageable environment that can be then replicated on a larger scale. For more information about smart cities, one should consult books in [22-28] and many others available on Amazon.com. One should also consult related journals: *Cities*, *Journal of Urban Technology*, and *IET Smart Cities*.

REFERENCES

- [1] V. Albino, U. Berardi, and R. M. Dangelico, "Smart cities: Definitions, dimensions, performance, and initiatives," *Journal of Urban Technology*, vol. 22, no. 1, 2015, pp. 3-21.
- [2] V. Albino, U. Berardi, and R. M. Dangelico, "Smart cities: definitions, performance, and initiatives," *Journal of Urban Technology*, vol. 22, no. 1, 2015, pp. 3-21
- [3] M. N. O. Sadiku, A. E. Shadare, E. Dada, and S. M. Musa, "Smart cities," *International Journal of Scientific Engineering and Applied Science*, vol. 2, no. 10, Oct. 2016, pp. 41-44.
- [4] P. Hayat, "Smart cities: A global perspective," *India Quarterly*, vol. 72, no. 2, 2016, pp. 177-191.
- [5] N. Villanueva-Rosales, "Semantic-enhanced living labs for better interoperability of smart cities solutions," *Proceedings of IEEE International Smart Cities Conference*, September 2016.
- [6] M. Rouse, "Smart city," <https://internetofthingsagenda.techtarget.com/definition/smart-city>
- [7] "Smart city," *Wikipedia*, the free encyclopedia https://en.wikipedia.org/wiki/Smart_city
- [8] A. Camero and E. Alba, "Smart city and information technology: A review," *Cities*, vol. 93, October 2019, pp. 84-94.
- [9] A. Babar, "Smart cities: Socio-technical innovation for empowering citizens," *Australian Quarterly*, July-September, 2016, pp. 18-25.
- [10] "Smart transportation," <https://www.brindleytech.com/smart-transportation/>
- [11] M. Usman et al., "A survey on big multimedia data processing and management in smart cities," *ACM Computing Surveys*, vol. 52, no. 3, June 2019.
- [12] S. P. Mohanty, U. Choppali, and E. Kougianos, "Everything you wanted to know about smart cities," *IEEE Consumer Electronics Magazine*, July 2016, pp. 60-70
- [13] M. N. O. Sadiku, S. M. Musa, and S.R. Nelatury, "Internet of things: An introduction," *International Journal of Engineering Research and Advanced Technology*, vol. 2, no. 3, March 2016, pp. 39-43.
- [14] S. P. Mohanty, U. Choppali, and E. Kougianos, "Everything you wanted to know about smart cities," *IEEE Consumer Electronics Magazine*, vol. 5, no. 3, 2016.
- [15] M. N. O. Sadiku, M. Tembely, and S. M. Musa, "Big data: An introduction for engineers," *Journal of Scientific and Engineering Research*, vol. 3, no. 2, 2016, pp. 106-108.
- [16] V. Albino, U. Berardi, and R. M. Dangelico, "Smart cities: Definitions, dimensions, and performance," <https://pdfs.semanticscholar.org/656e/4fb0564d96407161d9e541a9ca15375d6c60.pdf>
- [17] D. Loffreda, "Tomorrow's cities: evolving from 'smart' to adaptive," April 2019, <https://www.ciena.com/insights/articles/Tomorrow-cities-evolving-from-smart-to-Adaptive.html>
- [18] M. Batt et al., "Smart cities of the future," *The European Physical Journal Special Topics*, vol. 214, 2012, pp. 481-518.
- [19] M. J. Mulquin, "Roles of IEC in supporting effective smart city standards," *IET Smart Cities*, April 2019.
- [20] M. N. O. Sadiku, O. D. Olaleye, and S. M. Musa, "Green cities: A tutorial," *International Journal of Trend in Research and Development*, vol. 6, no. 3, May- Jun. 2019, pp. 77-79.
- [21] T. Yigitcanlar, "Smart cities: an effective urban development and management model?" *Australian Planner*, vol. 52, no. 1, 2015, pp. 27-34.
- [22] T. M. V. Kumar (ed.), *E-Governance for Smart Cities*. Springer-Verlag Singapur, 2015.

- [23] O. Gassmann, J. Böhm, and M. Palmié, *Smart Cities: Introducing Digital Innovation to Cities*. Emerald Publishing, 2019.
- [24] J. N. Pelton and I. B. Singh, *Smart Cities of Today and Tomorrow: Better Technology, Infrastructure and Security*. Copernicus, 2018.
- [25] M. Barlow and C. Levy-Bencheton, *Smart Cities, Smart Future: Showcasing Tomorrow*. John Wiley & Sons, 2018.
- [26] B. Green, *The Smart Enough City: Putting Technology in Its Place to Reclaim Our Urban Future*. MIT Press, 2019.
- [27] H. Sun, C. Wang, and B. I. Ahmad, *From Internet of Things to Smart Cities: Enabling Technologies*. Boca Raton, FL: 2017.
- [28] H. Song et al., *Smart Cities: Foundations, Principles, and Applications*. John Wiley & Sons, 2017.

ABOUT THE AUTHORS

Matthew N.O. Sadiku is a professor emeritus in the Department of Electrical and Computer Engineering at Prairie View A&M University, Prairie View, Texas. He is the author of several books and papers. His areas of research interests include computational electromagnetics and computer networks. He is a fellow of IEEE.

Tolulope J. Ashaolu is the author of several papers and two books. His research interests include functional foods and food microbiology.

Abayomi Ajayi-Majebi is a professor in the Department of Manufacturing Engineering at Central State University in Wilberforce, Ohio. In 2015 he was honored by the White House as a Champion of Change for his significant contributions to the engineering education of minority students. He is a senior member of both the Society of Manufacturing Engineers and the American Society for Quality.

Sarhan M. Musa is a professor in the Department of Electrical and Computer Engineering at Prairie View A&M University, Prairie View, Texas. He has been the director of Prairie View Networking Academy, Texas, since 2004. He is an LTD Sprint and Boeing Welliver Fellow. His areas of research interests include computational electromagnetics and computer networks.



FIGURE 1: Illustration of smart transportation [10].



FIGURE 2: Some components of a smart city [11].

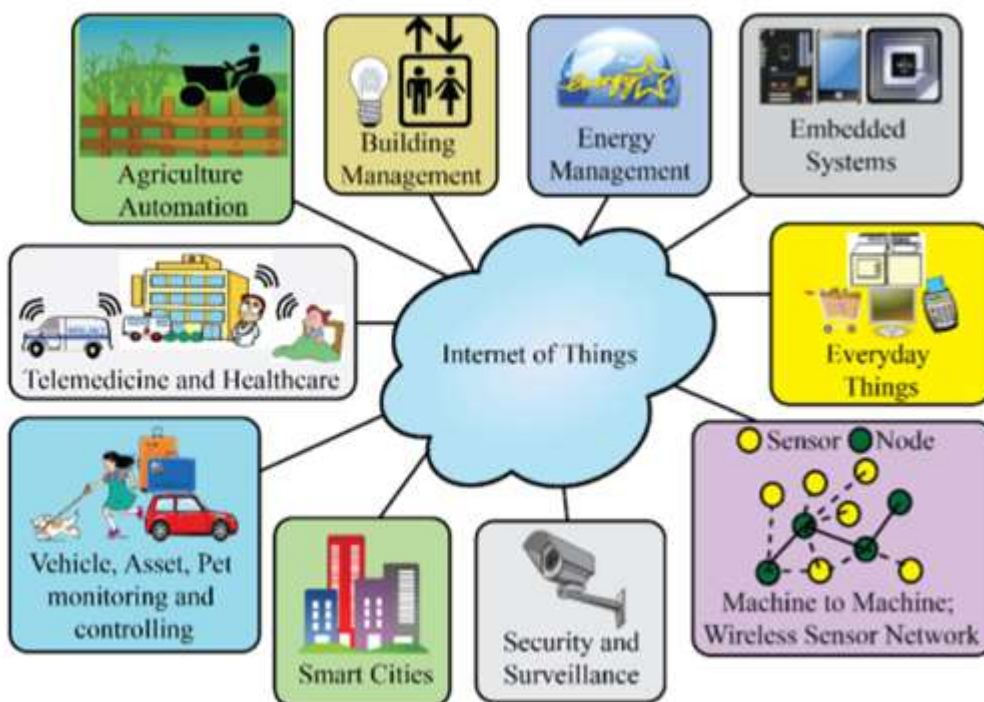


FIGURE 3: Internet of Things (IoT) in smart cities [14].