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Internet of Things in Smart Cities

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ABSTRACT
Cities around the world face growing pressure to provide reliable transportation, energy, water, sanitation, healthcare, and public safety services while controlling costs and protecting the environment. Traditional urban systems often operate independently and react to problems only after they have become visible. The Internet of things (IoT) offers a more intelligent approach. IoT refers to networks of physical objects—such as sensors, meters, cameras, vehicles, and household devices—that collect information and communicate through the Internet. In a smart city, these connected devices create a continuous flow of data that helps public authorities understand urban conditions, coordinate services, and make informed decisions. When implemented responsibly, IoT can make cities more efficient, sustainable, safe, responsive, and comfortable places to live. This paper presents a comprehensive overview on the transformative role of IoT in smart cities.

KEYWORDS: *smart cities, urban areas, Internet of things.*

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INTRODUCTION
The United Nations predicted that by 2050, about 70% of the world's population will live in urban areas. This rapid urban growth is placing increasing pressure on transportation networks, energy systems, public services, and the natural environment. In response, governments around the world are pursuing the idea of the smart city: an urban community that uses digital technologies and data to improve public services, sustainability, economic activity, and residents' quality of life. The Internet of things (IoT) is central to this transformation. It connects physical objects—such as traffic lights, vehicles, electricity meters, water pipes, buildings, cameras, and environmental sensors—to communication networks so that they can collect data, exchange information, and support automated or human decision-making. IoT systems are more than collections of connected gadgets; they are cyber-physical systems through which cities can observe conditions, coordinate services, and respond in near real time [1].

Smart cities are a technical solution to help city officials meet urban planning goals. To date, city officials have been able to use Internet of things technology to make certain aspects of their cities "smart," such as street lights, meters, and utilities. The mass deployment of technology is only one component of making a city smart. Ultimately, a smart city's success rests on how well connected devices and data are used to optimize the civilian experience. By this metric, the smart city of the future will leverage technology and IoT to become safer, more sustainable, and more efficient [2].

WHAT IS A SMART CITY?
Cities around the world are being wrecked by the ever-increasing burden of traffic. Smart cities are a recent innovation perceived as a winning strategy to cope with some severe urban problems such as traffic, pollution, energy consumption, waste treatment. Governments can streamline the way cities are run, saving money and making them more efficient as a result. The notion of the smart city captured most people attention during the last decade as a blend of beliefs on how technology in general could be used to transform how cities around the world work, while improving their competitiveness, offering new ways of solving problems linked to poverty, social

deprivation, pollution and poor environmental issues [3].

The concept of smart city emerges as a major response to the increasing global urbanization, global warming, sustainable growth, scarcity of resources, and socio-economic challenges faced by cities worldwide. IBM's Smarter Cities work began in late 2008 as part of the Smarter Planet initiative. The idea of "smart city" first appeared in the 1990s, with focus on the impact of ICT on modern infrastructures within cities. It is the merge of some other more familiar urban policies such as digital city, green city, knowledge city.

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.

As typically shown in Figure 1 [4], a smart city is a high-tech urban area that connects people, information and technologies in order to increase life quality. It integrates 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.

The main target for developing smart cities is to provide the following services [5]:
1. Convenience of the public services
2. Delicacy of city management
3. Liveable and sustainable living environment
4. Smartness of infrastructures
5. Effective integration of physical, digital and human systems in the built environment to deliver a sustainable, prosperous and inclusive future for its citizens.
6. Adequate water supply and electricity supply
7. Sanitation, including solid waste management
8. Efficient urban mobility and public transport
9. Affordable housing, especially for the poor
10. Good governance, especially e-Governance and citizen participation,
11. Safety and security of citizens, particularly women, children and the elderly
12. Health and education.

Figure 2 displays the six major characteristics of a smart city [6], while Figure 3 shows different elements of a smart city [7].

OVERVIEW OF INTERNET OF THINGS

The concept of the Internet of things (IoT) has been around since the late 1990s, but it gained momentum in the 2000s with the rise of Internet-connected devices. The Internet began with some military computers in the Pentagon called Arpanet in 1969. It expanded throughout the 1980s as a set of four parallel military networks, each at a different security level. The evolution of IoT is shown in Figure 4 [8]. The core technology which gives the Internet its particular characteristics is called Transmission Control Protocol/Internet Protocol (TCP/IP), which is essentially a set of rules for communication [9].

Internet of things (IoT) is a worldwide network that connects devices to the Internet and to each other using wireless technology. These devices contain hardware such as sensors and electronics which give them the ability to interact with other objects and to be monitored and controlled from afar. The idea is that the physical devices with sensors or the ability to capture data, shares that data with websites. The information is then used or analyzed in real time or at a later time, to create efficiencies. IoT is expanding rapidly and it has been estimated that 50 billion devices will be connected to the Internet by 2020. These include smart phones, tablets, desktop computers, autonomous vehicles, refrigerators, toasters, thermostats, cameras, alarm systems, home appliances, insulin pumps, industrial machines, intelligent wheelchairs, wireless sensors, mobile robots, etc. Figure 5 illustrates the Internet of things [10], while Figure 6 shows its various applications [11].

There are four main technologies that enable IoT [12]: (1) Radio-frequency identification (RFID) and near-field communication, (2) Optical tags and quick response codes: This is used for low cost tagging, (3) Bluetooth low energy (BLE), (4) Wireless sensor network: They are usually connected as wireless sensor networks to monitor physical properties in specific environments. Communications technologies in Internet of things are portrayed in Figure 7 [13].

IoT technology enables people and objects to interact with each other. It is employed in many areas such as smart transportation, smart cities, smart energy, emergency services, healthcare, data security, industrial control, logistics, retails, structural health, traffic congestion, manufacturing, and waste management. The Internet of things is extensively developed world-wide with a focus on civilian applications such as electric power distribution, intelligent transportation, healthcare, industrial control, precision agriculture, environmental monitoring, etc.

The growth of the internet of things (IoT) is drastically making impact on home and industry. While the IoT affects among others transportation, healthcare, or smart homes, the Industrial Internet of things (IIoT) refers in particular to industrial environments. IIoT is a new industrial ecosystem that combines intelligent and autonomous machines, advanced predictive analytics, and machine-human collaboration to improve productivity, efficiency and reliability. It is bringing about a world where smart, connected embedded systems and products operate as part of larger systems [14].

The industrial Internet of things (IIoT) refers to the application of the Internet of things (IoT) across several industries such as manufacturing, logistics, oil and gas, transportation, energy/utilities, chemical, aviation and other industrial sectors. A typical industrial Internet of things is shown in Figure 8 [15].

INTERNET OF THINGS IN SMART CITIES

The rapid growth of cities has created serious challenges in transportation, energy use, public safety, waste management, environmental protection, and the delivery of essential services. Traditional urban systems often operate independently and respond to problems only after they occur. The Internet of things (IoT) offers a different approach by connecting physical objects—such as sensors, meters, cameras, vehicles, streetlights, and household devices—to communication networks. These connected objects collect and exchange data, enabling city authorities to monitor conditions, automate operations, and make better-informed decisions. Connected sensors, lights, and meters allow cities to collect and analyze information that can improve city functions and residents' lives. In a smart city, IoT functions as a kind of urban nervous system: it senses changes in the physical environment and helps public institutions respond more quickly [1].

Smart cities rely mainly on the Internet of things (IoT) to make an urban area smart to offer its citizens a high quality of life with optimal use of resources and preservation of the environment. IoT is the key component that collects raw data on the surrounding environment to be analyzed to extract information that supports decision making. Figure 9 shows how IoT makes cities smarter [16], while Figure 10 shows the interconnection of IoT components in smart city scenarios [17].

APPLICATIONS OF INTERNET OF THINGS IN SMART CITIES

The Internet of things has wide-ranging applications in smart cities. It can improve traffic management, public transportation, energy distribution, street lighting, water conservation, waste collection, environmental monitoring, public safety, healthcare, building management, and government services. Common applications of smart city IoT include the following [1,18]:

- *Smart Transportation*: Transportation is one of the most visible applications of urban IoT. Quality of life in any urban area depends on the efficiency, safety, and sustainability of transportation. By reducing emissions and providing transportation data that cities can use to make smarter infrastructure decisions, IoT-connected vehicles can be a decisive force in the quest for connected cities. Sensors, connected traffic signals, roadside equipment, and vehicle-location data can reveal congestion patterns and help transportation agencies adjust signal timing or redirect traffic. IoT also improves public transportation. Public-transport operators can use real-time vehicle data to monitor routes, provide arrival information, and identify delays. Smart-parking systems can guide drivers toward available spaces, potentially reducing the time and fuel wasted while searching for parking.
- *Smart Citizenship*: City administrations can interact with citizens more successfully thanks to IoT. For example, users can obtain real-time information about events, public transportation, and more by using mobile apps to report problems. This encourages residents to actively engage in municipal life and builds a sense of communal commitment.
- *Smart Energy*: In order to optimize energy consumption in smart cities, IoT is essential. Smart meters and Internet of things (IoT) sensors allow buildings to modify temperature, lighting, and air conditioning in response to occupancy and outside factors. Residents and companies save money as a result of this, which also lowers energy waste. IoT also contributes to better energy management. Smart meters allow residents, businesses, and utility companies to observe electricity consumption in much greater detail than conventional meters. IoT can help cities reduce energy waste through smart grids and connected meters. Smart meters provide detailed information about electricity

consumption, while sensors throughout the grid can detect faults, equipment stress, and unusual demand. Utilities can use this information to balance supply and demand, restore service more efficiently, and integrate distributed renewable-energy sources. Consumers can also receive timely information about their energy use and adjust their behavior accordingly. Smart street lighting is a practical example of IoT-based energy management. Connected lamps can dim when streets are empty and brighten when pedestrians or vehicles approach.

- *Infrastructure Management*: IoT also enables more intelligent management of energy and physical infrastructure. Smart meters can provide detailed information about electricity use, while connected grid equipment can help utilities balance supply and demand and identify faults. Building-management systems can use occupancy, temperature, and lighting data to reduce unnecessary energy consumption. Similarly, connected streetlights may brighten when pedestrians or vehicles are present and dim when an area is empty, thereby conserving electricity without abandoning public safety. Smart grids, energy management, building automation, structural monitoring, and smart lighting are all established areas of IoT research and deployment. Used carefully, these technologies can lower operating costs, conserve resources, and support environmental goals.
- *Environmental Monitoring*: Environmental monitoring and municipal services employ urban IoT. A network of environmental sensors can provide continuous, location-specific measurements of air pollution, noise, temperature, humidity, rainfall, and water conditions. City authorities can use this data to identify pollution hotspots, evaluate environmental policies, and warn residents about harmful conditions. Distributed sensors can measure air pollution, noise, heat, rainfall, and water quality at a level of detail that would be difficult to achieve through occasional manual surveys. Connected waste bins can report when they are full, allowing collection routes to be planned according to actual demand rather than fixed schedules. Sensors in water networks can help identify leaks or abnormal pressure, while monitoring equipment can give earlier warnings of floods or infrastructure failures. Figure 11 shows air pollution [20].
- *Public Health:* Public health and safety can also benefit from connected technologies. Wearable or home-based medical devices can support remote monitoring, especially for older adults or people with chronic conditions, while connected systems may help emergency services allocate resources and choose faster routes. Healthcare and structural monitoring are recognized applications of smart-city IoT. Nevertheless, these uses raise particularly serious ethical questions because health, location, and behavioral data can be highly sensitive. A technically effective system may still be socially unacceptable if residents believe that it subjects them to constant surveillance or uses their information without meaningful consent.
- *Water Supply:* A major advantage of urban IoT is the more efficient management of water and waste. Water systems benefit from connected flow, pressure, and quality sensors. These devices can identify unusual changes that may indicate leaks, pipe damage, contamination, or unauthorized consumption. Early detection allows utilities to respond before a small fault becomes a costly failure. Smart irrigation systems can combine soil-moisture measurements with weather information to water parks and public gardens only when necessary. In regions experiencing water scarcity, such capabilities can support conservation while maintaining public spaces.
- *Waste Management:* Populated countries face difficulties to dispose of their wastes effectively. IoT enabled waste management solution segregates renewable and non-renewable wastes to resolve ineffective waste collection issues. Waste collection can also become more efficient through IoT. Fill-level sensors in public bins and containers can inform sanitation departments when collection is required. Instead of following a rigid schedule, collection vehicles can be directed along routes based on actual need. This reduces unnecessary trips while helping prevent overflowing bins. Similar tracking technologies can monitor recycling, hazardous waste, and municipal equipment, improving accountability across the waste-management process.
- *Emergency Response*: Connected smoke detectors, flood gauges, structural sensors, surveillance systems, and emergency call devices can alert authorities to dangerous situations as they develop. During a fire, flood, accident, or security incident, real-time information can help emergency teams determine where assistance is needed and identify the fastest route to the scene. Sensors on bridges, roads, tunnels, and public buildings can also detect unusual vibration, movement, temperature, or material stress. This

preventive approach is safer and often less expensive than repairing infrastructure after serious damage has occurred.

BENEFITS

One of the most important benefits of IoT is the improvement of urban transportation. Traffic sensors, connected traffic lights, GPS-equipped buses, parking sensors, and road cameras can provide real-time information about vehicle movement and congestion. Other benefits of smart city IoT include the following [1,19]:

- *Public Safety*: IoT can strengthen public safety by connecting emergency alarms, smoke detectors, cameras, structural sensors, and communication systems. When an incident occurs, these devices can provide emergency services with timely information about its location and severity. Sensors in bridges, tunnels, and public buildings may detect vibration, movement, heat, or structural deterioration, allowing authorities to inspect critical infrastructure before a failure occurs. During disasters, connected warning systems can distribute alerts and help coordinate evacuation, rescue, and recovery operations. In healthcare, connected devices can support remote monitoring of patients, older adults, and people with chronic conditions.
- *Energy Efficiency*: IoT technology enables meticulous monitoring and efficient management of energy consumption in buildings and public spaces. This leads to reduced energy wastage and substantial cost savings. IoT technologies facilitate the development of smart grids that optimize energy distribution and consumption. Smart meters enable consumers to monitor their energy usage and adjust accordingly, promoting energy conservation. Additionally, integrating renewable energy sources with IoT can lead to more sustainable urban environments, significantly reducing the carbon footprint of cities.
- *Environmental Sustainability*: Although IoT can help reduce energy use, emissions, water loss, and waste, the infrastructure itself has an environmental footprint. IoT can support environmental sustainability. Networks of sensors can continuously measure air pollution, noise, temperature, humidity, and water quality across different neighborhoods. Instead of relying only on occasional inspections or a small number of monitoring stations, city officials can develop a more detailed picture of environmental conditions. This makes it easier to identify pollution hotspots, evaluate environmental policies, warn residents about hazardous conditions, and plan greener neighborhoods. By connecting environmental monitoring with transportation, energy, and land-use planning, IoT helps cities address sustainability as an integrated challenge rather than as a series of separate problems.
- *Public Trust:* Public trust is essential because residents are more likely to resist smart-city projects if they believe that the technology is secretive, discriminatory, or intrusive. Cities must adopt privacy by design, collecting only necessary data and protecting it throughout its life cycle. They should also conduct privacy-impact assessments, publish understandable data policies, establish independent oversight, and provide ways for citizens to question or challenge the use of their information. Transparency cannot eliminate every privacy risk, but it can make public authorities more accountable.

CHALLENGES

In spite of the significant potential of IoT in smart cities, numerous challenges hinder its widespread implementation. Challenges such as cybersecurity threats, privacy risks, heterogeneity, scalability, security, incompatible systems, poor-quality data, high life-cycle costs, weak governance, digital inequality, and environmental impacts hinder the efficient functioning of the IoT in the construction of smart cities. Other challenges of smart city IoT include the following [1,17]:

- *High Cost:* We all know just how costly keeping an entire city of devices connected would be — not to mention the costs of implementing connectivity, to begin with. Building a solution of this scale from scratch would be an immense undertaking, though most traditional telecom providers do not have the means or pricing structure to make smart city connectivity financially realistic. Smart-city projects involve more than the initial purchase of sensors. They require communications infrastructure, cloud or edge-computing capacity, cybersecurity services, software licences, skilled staff, power, maintenance, and eventual replacement.
- *Privacy Concerns*: Privacy presents an equally important challenge. Even when a sensor does not record a person’s name, repeated observations of location, movement, energy use, or device identifiers may reveal sensitive behavior. Urban sensors can collect information about where people travel, which services they use, and how they behave in public or private spaces. Cities must clearly define what information is collected,

why it is needed, how long it is retained, who may access it, and how residents can challenge misuse.

- *Data Quality:* IoT systems are valuable only when the data they produce are sufficiently accurate, timely, relevant, and understandable. Sensors can deteriorate, lose calibration, become damaged, or generate incomplete readings. Network interruptions may delay information, while inconsistent formats can make datasets difficult to combine. Poor-quality data may then lead to poor decisions. For example, inaccurate traffic data could cause an adaptive signal system to worsen congestion instead of reducing it.
- *Cybersecurity*: Cybersecurity is one of the most serious challenges confronting IoT-based smart cities. Security is one of the significant challenges, given how quickly IoT-connected devices are growing. The smart grid is vulnerable to significant attacks because the gadgets are online. Because the devices are online, the smart grid is susceptible to severe attacks. Each connected device can become a potential point of entry into a larger network. Weak passwords, outdated software, insecure communications, and poorly managed vendors may expose systems to theft, manipulation, or disruption. The consequences can be more serious than those of a conventional data breach because IoT systems may monitor or control physical infrastructure. An attack affecting traffic signals, water systems, healthcare equipment, or the electricity grid could endanger public safety. Security must therefore be designed into the entire lifecycle of a system, including device authentication, encrypted communication, access control, software updates, continuous monitoring, incident response, and the secure retirement of obsolete equipment.
- *Interoperability*: Interoperability is a persistent barrier. A city may purchase devices from many vendors, each using different data formats, communication protocols, and software platforms. The lack of interoperability produces data silos, duplication, and vendor dependence. It can also prevent cities from obtaining a complete picture of urban conditions. Without common standards, systems may be unable to exchange information, and governments may become dependent on a single supplier. NIST emphasizes standards-based foundations that make smart-city systems interoperable, replicable, scalable, and trustworthy. Open standards and well-defined interfaces can help cities integrate new technologies, compare performance, and avoid rebuilding entire systems whenever a component changes.
- *Lack of Encryption*: Even though encryption is a great way to prevent thieves from acquiring data, it presents one of the significant security concerns for IoT. These drives are used for a typical computer's processing and storage power, and the ultimate result is increased attacks where hackers may swiftly alter the security algorithms.
- *Reliability:* The IoT-based system has experienced a few dependability problems. For example, vehicle communication is not dependable enough due to their mobility. Additionally, the proliferation of smart gadgets will provide certain dependability issues in terms of their failure.
- *Inequality:* Smart-city policy must address inequality. Digital services may be an advantage to residents who have reliable internet access, modern devices, and strong digital skills while excluding lower-income households, older adults, people with disabilities, or marginalized communities. Cities should therefore evaluate who benefits, who bears the risks, and who participates in decisions. Non-digital alternatives should remain available for essential services, while procurement and performance measures should include accessibility, affordability, geographic fairness, and community-defined outcomes. A city cannot be considered genuinely smart if technological progress makes public services less inclusive. Democratic accountability is equally important.
- *Complexity:* Technological complexity makes responsibility harder to assign. When an automated service fails, the cause may lie in the sensor, communications network, cloud platform, analytical model, or decisions made by a contractor. Municipal governments need sufficient technical expertise to supervise this chain of systems rather than depending entirely on vendors. Without such expertise, cities may purchase impressive technologies that cannot be integrated, audited, or maintained effectively. Urban systems operate in complex social environments in which an apparently efficient decision may distribute benefits and burdens unfairly.

FUTURE OF INTERNET OF THINGS IN SMART CITIES

The future of smart cities is closely tied to ongoing advancements in IoT technology. The future of IoT in smart cities will not be defined simply by installing more sensors. A city can be highly connected yet remain inefficient, unequal, insecure, or unresponsive to its residents. The future will likely involve closer integration with artificial intelligence, edge computing, advanced communications, and digital twins. IoT will reach its greatest value when it is combined with artificial intelligence, edge computing, digital twins, open standards, strong cybersecurity, and democratic data governance. Artificial intelligence can help identify patterns, predict failures, and optimize complex systems, while digital twins can support simulation before changes are introduced into the physical city. Edge computing processes at least part of the data close to where it is generated rather than sending everything to a distant cloud platform. This can reduce delay, limit bandwidth use, improve resilience during network disruption. Cities should adopt technology incrementally, test it under real conditions, publish measurable goals, and discontinue projects that fail to create public value. The next generation of IoT will connect sensing with edge computing and artificial intelligence [1].

CONCLUSION

The Internet of things can help cities become more efficient, sustainable, safe, and responsive by connecting infrastructure, collecting real-time data, and enabling coordinated action. The applications of urban IoT extend from traffic management and smart grids to environmental monitoring, healthcare, water systems, waste collection, and predictive maintenance. When these systems are designed to work together, IoT can make cities more efficient, sustainable, responsive, and convenient.

The ultimate purpose of a smart city should not be to automate urban life for its own sake. It should be to expand human opportunity, strengthen resilience, improve public services, and give communities greater capacity to shape their surroundings. The most successful smart cities will be those that combine technological capability with cybersecurity, privacy protection, open standards, institutional competence, transparency, and social inclusion. The most successful smart cities will be those that treat IoT as a means rather than an end. More information on IoT in smart cities can be found in the book in [20-27] and the following related journals:

- Cities
- Internet of Things
- Sensors

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Figure 1 A typical smart city [4].

Figure 2 The six major characteristics of a smart City [6].

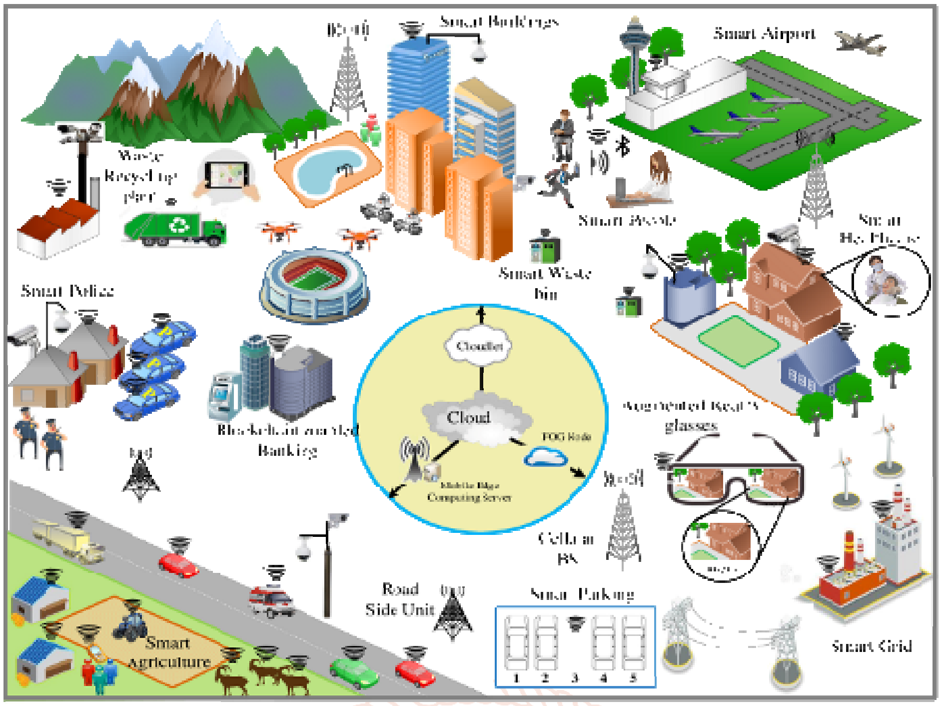

Figure 3 Different elements of a smart city [7].

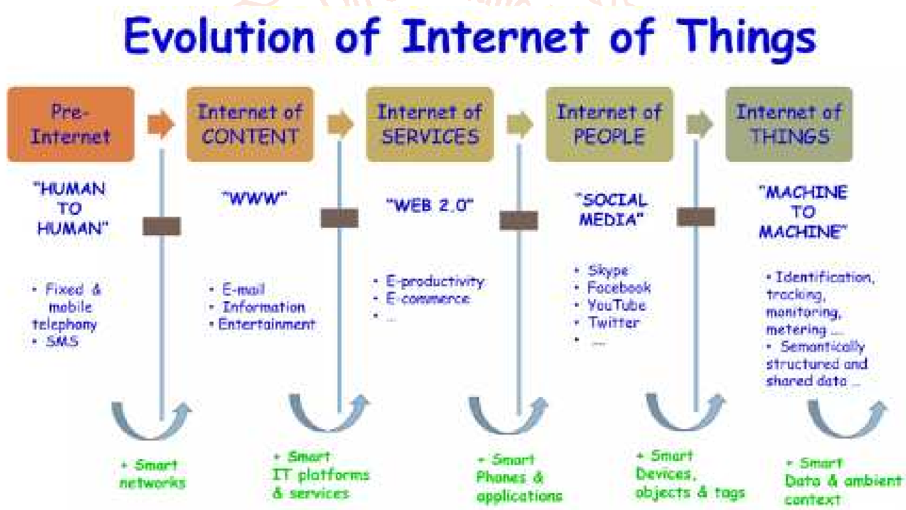

Figure 4 The evolution of IoT [8].

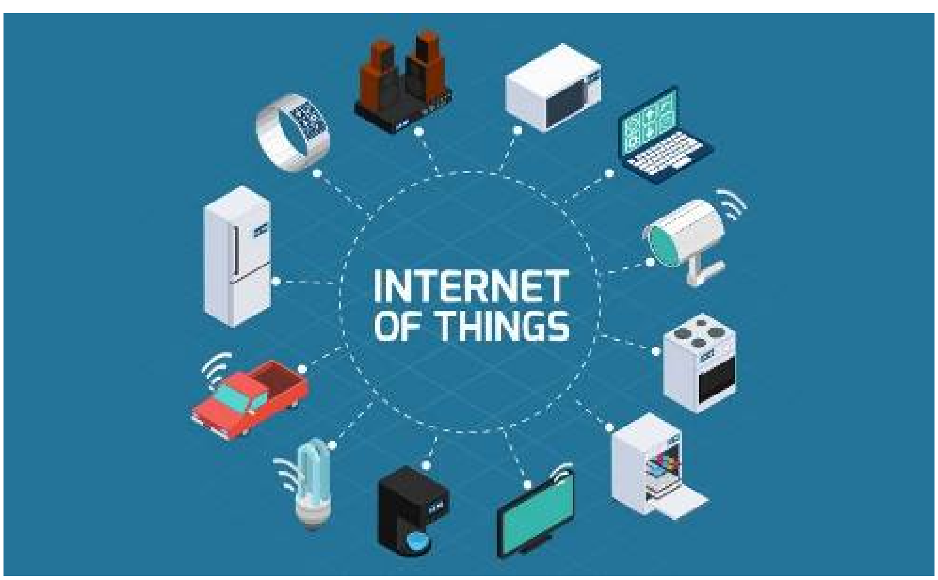

Figure 5 The Internet of things [10].

Figure 6 Applications of IoT [11].

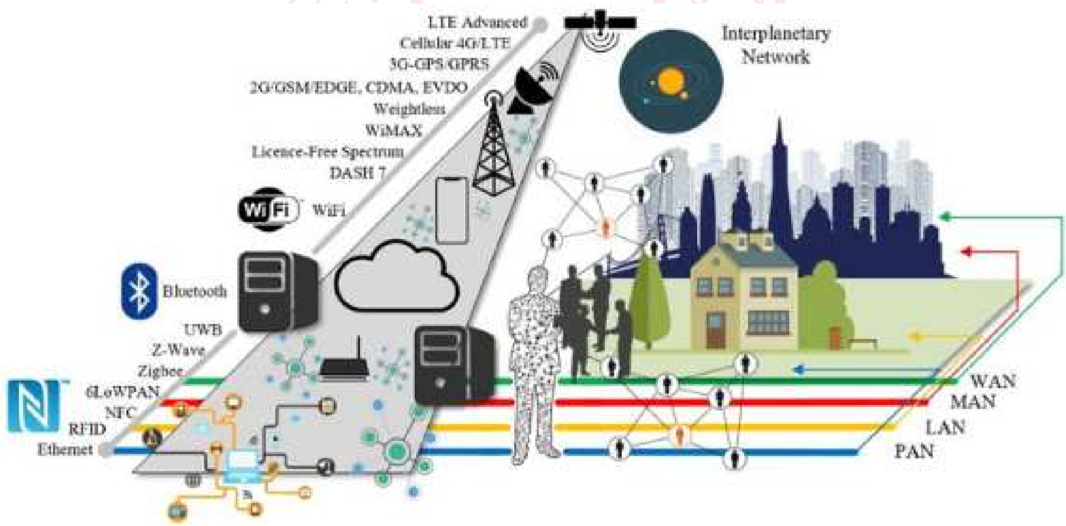

Figure 7 Communications technologies in Internet of things [13].

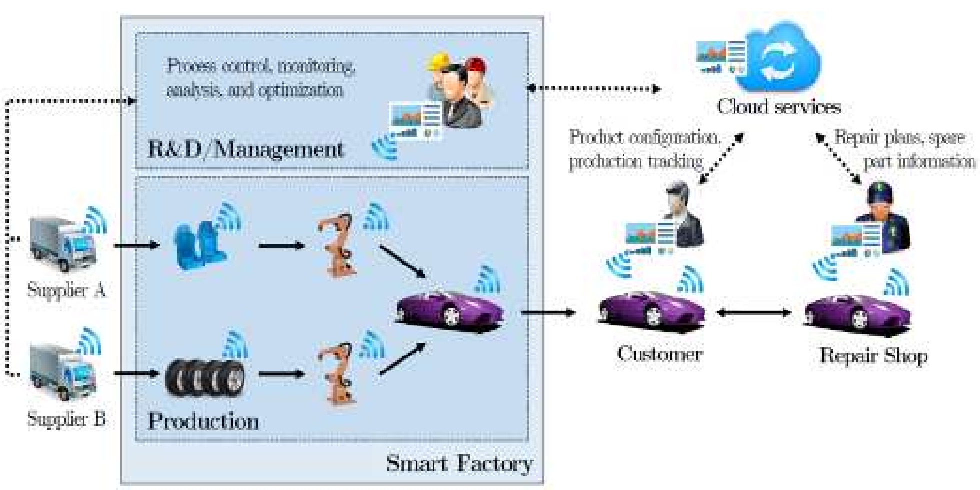

Figure 8 A typical industrial Internet of things [15].

Figure 9 How IoT makes cities smarter [16].

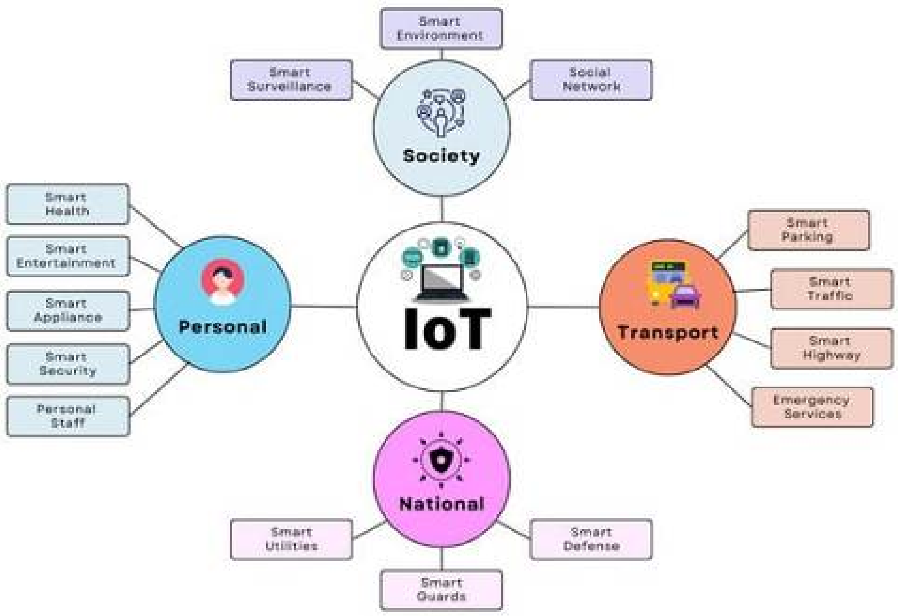

Figure 10 Interconnection of IoT components in smart city scenarios [17].

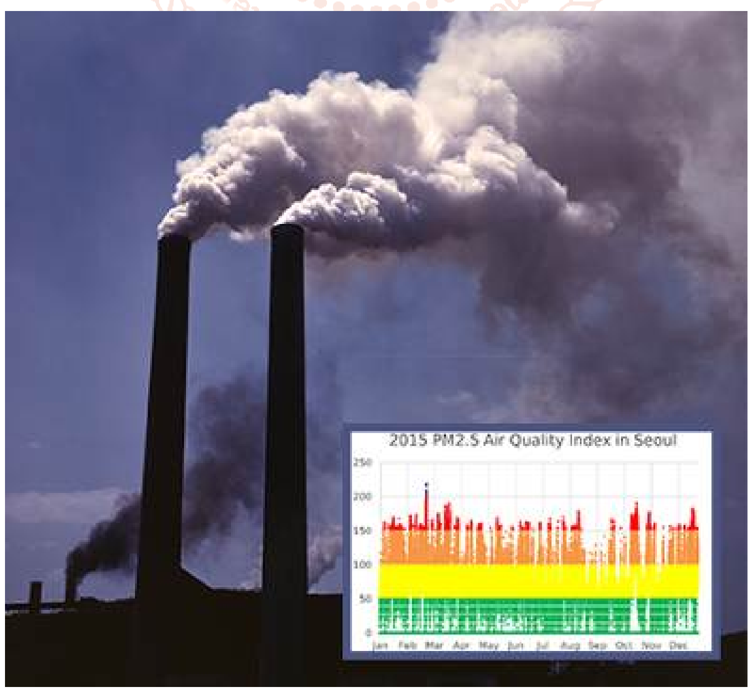

Figure 11 Air pollution [16].