Recent Advances in Smart City Using IoT and 5G Mobile Network

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Abstract-- **A smart city aims to improve quality of life for its citizens by harnessing technology to connect infrastructure, resources and services. The smart city uses Internet of Things (IoT) technology, where connectivity is truly ubiquitous and generates real benefits to those living and working in the city. The list of connected IoT devices expands to include every aspect of living and working in the city which is able to manage environment to make it safer, cheaper, and more convenient to citizens. A reliable communication is required in a fully integrated connected smart city to make it sustainable, livable, competitive and resilient, helping to meet current and future challenges. In this paper, an urban IoT technology is focused to support the smart city vision, which aims to exploit the most advanced communication technology to support added-value services for citizens. This paper provides comprehensive survey of the enabling technologies, architecture of urban IoT technology and use cases.**

Keywords: IoT, Digital Twin, 5G, Congestion, Citizen, Smart parking, Smart lighting, Waste management

I. INTRODUCTION

CURRENTLY, nearly 55% of the world population inhibit urban areas and is expected to increase to 68% by 2050. Additionally rural-to-urban migration in search of employment and better living conditions could contribute nearly 2.5 billion more people to urban areas by 2050 (Ref.: World Urbanization Prospects, 2018). A city generates more than 80% of global GDP, considered to be the main engine of global economic growth. Because of urbanization, cities consume 2/3 of global energy consumption which accounts for more than 70% green house gas generation (World Bank 2020). As the urban populations continue to grow, cities are facing unprecedented challenges in managing resources, infrastructure and sustainability. To address these issues, the concept of smart cities is rapidly gaining traction. A smart city leverages the technology to enhance the quality of life for its residents, improve operational efficiencies, and promote environmental sustainability. A smart city uses digital technologies to optimize the management of city assets, including transportation systems, energy grids, waste management, water supply and public services. These technologies rely heavily on data collection and analysis to make real-time decisions that improve efficiency, reduce waste, and enhance the overall quality of life for the residents.

Smart cities are designed to tackle urban challenges, such as traffic congestion, pollution, energy consumption, and public safety. By bringing data together and harnessing the power of real-time monitoring, the city can save money, achieve sustainability goals, and make the city healthier and happier place to live and work. The technology is rapidly becoming integral to every facet of city operations. Whether it is helping to reduce carbon impact, defend against cyber-attacks, optimize both energy performance and occupant well-being, or make communities more resilient in times of crisis, it can provide competitive business advantage as well as help to reduce operating expenses. The Indian Government planned investment of about $1 million for hundred smart cities in different regions over the next five years in June, 2015 [1]. In this paper, section 2 discusses Internet of Things while section 3 discusses artificial intelligence. Section 4 discusses fifth generation mobile network while section 5 discusses digital twin. Section 6 discusses various use cases of smart city and finally Section 7 concludes the paper.

II. INTERNET OF THINGS

The Internet of Things (IoT) lies at the heart of the smart city. The IoT is a network of interconnected IoT devices that gathers information from a multitude of sensors, cameras, and other devices located on buildings, light poles, parking spaces, sewer pipes, electricity meters, dumpsters, and many other locations in the city. The actuators take action on the changes required in the environment, the micro-controller to process the sensors data, the transceivers to transmit processed sensors data and receive actuator commands. The Gateway handles communication with above IoT sensors and actuators, and shares data in real-time to the cloud. This gateway requires high performance microprocessors to evaluate data received from sensors and determine whether to take action locally? The gateways may require high speed multi-channel communication to transmit data to the cloud. The cloud includes multi-core microprocessor with hardware GPU (General Processing Unit) for signal processing tasks. The cloud interfaces with multiple gateways and performs analysis on the collected and pre-stored data. It monitors and manages IoT ecosystem. It processes the data-streams to control operations of the various functions. The end-user interface allows access and control of IoT products

and services. The IoT plays a pivotal role in transforming cities into smarter, more sustainable urban environments [2]. It plays a key role in this process by enabling communication between various systems and devices, allowing for smarter decision-making and more responsive city services.

A Smart City uses digital technologies to optimize the management of city assets. These technologies rely on the data collection and analysis to make real-time decisions that improves the efficiency as shown in Fig.1. The IoT enables smart cities by converting physical infrastructure to digital platforms, creating a real-time flow of data that cities use to improve operations [3]. From intelligent street lighting to traffic management and waste collection as shown in Fig.1, IoT technologies are revolutionizing how cities function? The falling costs, increased accessibility, and greater sophisticated IoT devices have made it easier to generate data for the superior performance of the cities. By leveraging the power of IoT, cities can address the complex challenges of modern urbanization while improving the quality of life for residents. As urban areas continue to grow and evolve, the integration of IoT technology will be essential in building cities that are not only smarter but also safe, more sustainable and livable.

III. ARTIFICIAL INTELLIGENCE

At its core, the IoT enables different components to communicate with each other without any intelligence. This has created a prime opportunity to apply artificial intelligence (AI) to turn data into actionable information as shown in Fig. 1. Without intelligence, the data from cities is either time-consuming or deemed not useful information. The AI is brain behind the operation, providing predictive analysis, automation, and decision making [4], while IoT is the digital nervous system providing passive sensing, data generation, and connected ecosystem. Further predictive analytics powered by 5G mobile network enabled IoT and AI, the system helps cities anticipate and address issues before they become problems, resulting in more proactive maintenance and service delivery.

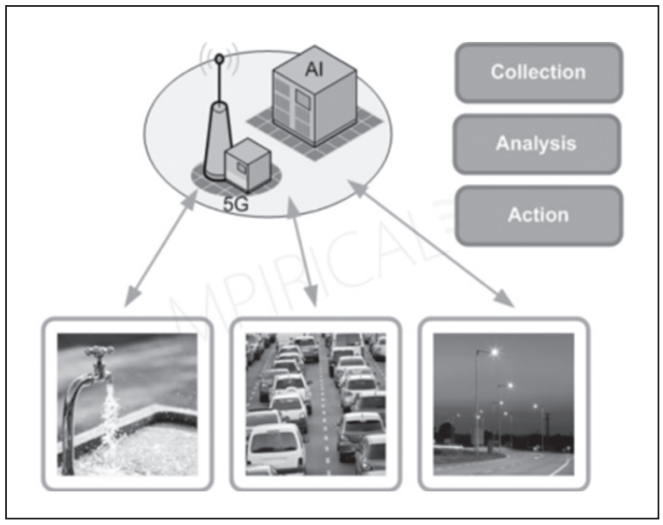

Figure 1. Smart City Using IoT, AI and 5G

By analyzing the vast amounts of data collected by IoT devices, AI systems can predict and solve urban challenges more effectively, from traffic congestion to energy consumption and beyond. The AI builds smart machines that can perform and process human-like tasks and learn over time to adjust tasks to gain more accuracy and efficacy. The convergence of the 5G cellular technology, AI, and cloud computing is driving significant advancements in smart city management and energy efficiency solutions.

The 5G network promises to support the above requirements. This synergy enables real-time monitoring, automated controls, and data driven insights, transforming the city to operate and manage energy consumption. The combination of 5G with IoT, AI, and other intelligent technologies can benefit the smart city with high efficiency, high reliability, and sustainable development.

IV. FIFTH GENERATION MOBILE NETWORK

The development of the fifth generation (5G) networks will further enhance the capabilities of IoT devices, enabling faster, more reliable communication between connected systems as shown in Fig.1. This will allow smart cities to implement even more sophisticated solutions, such as autonomous vehicles, advanced energy storage systems, and smart infrastructure that can repair itself. The 5G mobile network is all about enhanced mobile broadband, low latency, and enable hundreds of thousands of sensors in identified area. The 5G will provide the necessary high speed, low latency connectivity that IoT devices require to operate efficiently with ability to support a massive number of devices. The 5G will enable seamless communication between sensors, machines, and systems allowing everything from smart traffic lights to environmental monitoring sensors to function in real-time [5]. The 5G uses wider BW through sub-6GHz and milimeter wave (>20GHz) spectrum to provide 20Gbps peak data rate, 1ms latency, and 1 million devices per square km with 99.9999% reliability. The 5G technology with reduced latency and increased speed and reliability is expected better IoT applications for intelligent cities technology over the years to come. The 5G not only improves speeds and lowers the latency but also has the ability to connect massive amounts of sensors and to process that information in real-time. The 5G alternative technology includes WiFi, Bluetooth, ZigBee, and LPWAN (Low power Wide area network) but 5G will continue to compete with respect to sensor density required for big data analytics. The 5G will be a key technology that will enable the full implementation of IoT in smart city. The 5G use cases including augmented Reality(AR)/VR(Virtual Reality), HD-Video, image analytics, drones, computer vision, cloud computing, digital twin, will require high BW to support seamless real-time analysis, low

latency for real-time communication [4]. It enables efficient and economical use of resources, while creating a safe and comfortable environment for citizens.

V. DIGITAL TWIN

The digital twin (DT) is a replica of physical identity that can think, sense and act in real-time, and suggest optimization. The DT stays up-to-date with information from real-objects and helps to find the best ways to improve it in real-time. The digital twin integrates the physical world with the virtual one by using 3D- visualization technology to create a high precision digital model that enable real-time monitoring, prediction, and maintenance of these assets or processes. With 3D-visualiztion technology, the assets or processes in the physical city can be converted into 3D-model in virtual city and presented in a more intuitive manner. To achieve the digital representations, it uses sensors to monitor devices operation and lives throughout the life cycle. It is based on a huge amount of data flowing from various systems, sensors, and software. The digital twin uses a series of integration with IoT, AI, ML (Machine Learning), and software analytics [6]. The rise of AI/ML will play a critical role in the future of smart cities. The DT applications need high speed connectivity to perform various tasks in real or short processing time. The 5G network can address problems faced by digital twin by providing massive data connectivity with security and cloud processing in the real time. The 5G and future mobile networks accessibility allow to access and manage DT from anywhere using mobile device. It enables updates in real-time between physical devices and the DT. The AI/ML enhances DT capabilities and effectiveness.

VI. USE CASES

Smart Lighting: A smart city tracks power consumption in various parts of city throughout the day and night. The IoT-powered street lighting systems can significantly reduce energy consumption by automatically adjusting the brightness of street lights based on ambient conditions or human activity [7]. These systems can detect when streets are empty and dim the lights to save energy, while increasing brightness when pedestrians or vehicles are detected. Lights can be dim or turned-off based on the activity. The city authorities can keep real-time tracking of lighting to ensure optimized illumination and deliver demand-based lighting in different zones. It improves safety by increasing lighting in the higher crime areas. The smart lighting also helps to save energy by dimming out sectors with no occupancies, for example, parking lots can be dimmed during working hours and when car is entering, it will be detected, and appropriate sectors can be illuminated, while others can be kept at diffused setting. Such facilities allow cities to deliver their citizens a high quality of life, while improving city finances.

Power and Energy: Power and energy management helps to manage, control, and optimize the energy usage of all the systems within a city that draw power [8]. According to US Energy Department as much as 30% of electrical usage in commercial cities is wasted due to inefficient lighting. Advanced smart energy sensors and meters monitor energy usage, optimize electricity distribution, and integrate renewable energy sources like solar and wind power. They provide continuous feedback on temperature, carbon level, humidity, and air pressure, and deliver information through gateways to cloud to provide a holistic view of the city performance. By analyzing data from homes, businesses, and power plants, power grids can reduce energy waste, lower cost, and ensure a more resilient energy supply. The IoT allows building managers and homeowners to monitor and optimize energy use through smart meters and connected thermostats.

Smart Transportation and Traffic Management: Urban traffic congestion is a growing problem in most of the big cities, causing millions of hours of travel delays, which translates into productivity losses. This issue affects the air quality and energy consumption. Most congestion is predictable at about same place, same time every day, but 25% congestion is non-recurring. It is caused by accidents, bad weather, road construction, etc. Heavy congestion in the cities results in drivers spending more than 70 hours or more per year in a grid lock with 4 to 6 kmph vehicle speeds at peak hours. The WHO estimated that 3 million deaths every year are attributes to small particulate matter (PM) pollution. High level of congestion results in high level of harmful pollutants in the air. The IoT- enabled sensors, cameras, and GPS systems installed on the roads and the vehicles, provide cities with real-time public traffic data. This data is then analyzed to optimize traffic flow, reduces both recurring and non-recurring congestion and emission, and improves public transportation efficiency. The cameras apply digital image processing and algorithm to aid in the prediction of traffic density.

Smart traffic lights can adjust signal timing based on real-time traffic conditions, allowing for smoother traffic flow during rush hours [9, 10]. The drivers traveling in non-peak hours need not wait at red light based on per-existing schedules. It also helps in improving air quality and providing safety for the elderly people. The IoT sensors embedded in roads can count number of vehicles at the traffic light crossing, monitor vehicle speeds, while connected vehicles can communicate with traffic infrastructure to adjust routes and avoid congested areas [11]. The vehicle-to-everything (V2X) infrastructure enable vehicles to communicate with multiple devices in real-time [12]. The traffic management system can analyze real-time data from vehicles (V2V) alerts one vehicle to the presence of another, pedestrian (V2P) communicate with vulnerable road users, infrastructure (V2I) alerts vehicles to traffic lights, traffic congestion, road conditions, networks (V2N) communicates directly with back-end or broadband Internet, and sensors to optimize traffic flow to reduce congestion, potential hazards, and optimize routes leading to the safer and more efficient

transportation [13]. The V2X hardware has an onboard unit (OBU) in the vehicle which communicates with other vehicles and the road side unit (RSU) to exchange message such as speed, brake status, direction, etc. The RSU also collects information of surrounding vehicles, pedestrians, and road conditions [14,15].

Drivers looking for parking space cause around 30% of traffic congestion as per ITS, USA. A smart parking system consists of cameras, ground-embedded sensors, GPS, and smart phone apps that can give real-time information on availability of parking space [16]. The faster time to locate a parking slot means fewer CO_2 emission from the car, lesser traffic congestion, and happier citizen. It helps to save time and increase revenue via demand-sensitive pricing. The GPS system in car directs to the closest parking spot seamlessly to save both time and fuel. This enables drivers in the malls and city-centers to find available parking space. The ground embedded sensors transmit data on timing and duration of the space used into central parking management [17]. Smart parking reduces congestion, decrease vehicle emissions, lower enforcement costs, and reduce driver stress. The smart parking meters connected to the light poles can eliminate cost associated for roadside parking [18].

Waste Management and Sustainability: Waste management is a critical issue in urban areas, where the amount of waste (garbage) generated continues to increase alongside population growth. This increases both cost of service and problem of the storage of garbage in landfills [19]. Open garbage bins becomes a breeding ground for germs and insects which spread numerous diseases. In many areas, garbage bins are not cleaned and maintained regularly. The IoT offers a solution by enabling smart waste management systems that monitor waste levels and optimize collection routes. The garbage bins with ultrasonic sensors placed on the lid detect the garbage level in the bins [20]. Once the garbage in the bin reaches the set limit the buzzer get pressed which further sends an alert to waste collection trucks mounted with a tablet to only service those that need emptying. This reduces unnecessary trips, ensuring timely disposal and recycling, lowering the fuel consumption, and minimizing the traffic congestion and emission [21]. The AI system can analyze waste patterns to help cities improve recycling rates and reduce landfill use. By optimizing waste collection and disposal, IoT contributes to more sustainable cities, reducing the environmental impact of waste management, and promoting cleaner, more efficient urban living.

Water Management and Conservation

Water is a precious resource, and many cities face challenges in managing their water supply efficiently. The IoT is playing an important role in water management by enabling smart water systems that monitor consumption, detect leaks, and optimize irrigation. IoT sensors installed in water pipelines can detect leaks in real time, allowing cities to quickly address issues and reduce water waste. Smart meters can provide residents with detailed insights into their water usage, promoting conservation by helping them identify opportunities to reduce consumption. In urban landscaping, the IoT- powered irrigation systems use weather data, soil moisture sensors, and AI-predictive analytics to optimize water usage, ensuring that plants receive just the right amount of water at the right time. This reduces water waste and supports more sustainable water management practices in both urban and rural environments. The smart sprinkler system synchronized with connected technology to water plants, to get right amount of water to smart public gardens. Smart garden devices measure soil moisture and level of fertilizer to help the city authorities to save on water bills and keep grass from overgrowing. The weather sensors automatically adjust sprinkler schedule to stay off when it rains. Smart city includes monitoring water quality for pollutants by using corresponding sensors to maintain quality of water. The sensors measure key variables such as salinity, pH, and chlorine levels and send alert to field workers through their mobile devices [22].

Public Safety and Emergency Response: The IoT technology is enhancing public safety by enabling smarter, more responsive emergency services. The connected cameras, sensors, and communication systems provide real-time data to law enforcement and emergency responders, improving response times and situational awareness. The IoT sensors can detect unusual activity, such as fires, flooding, or gas leaks, and immediately notify emergency services. The fire includes technology to monitor temperature, smoke, and fire detection, fire brigade operations, and/or communication with first responders. Smart fire sensors can detect and inform firefighters and ambulance helping people to evacuate, and coordinate drones and robots [23]. The AI-powered video security transforms existing IP camera into smart security system, offering enhanced surveillance, object counting, traffic insights, intrusion detection, facial recognition, license plate recognition, etc.

Healthcare: Smart healthcare devices can be implemented at public places to provide 24x7 healthcare for patients like dispensing medicines and drugs to patients. The local community centers can act as remote clinics where patients are able to use these monitoring devices, thus avoid unnecessary one-to-one physician visits [24]. Individuals suffering from chronic disease will often have to visit physician multiple times per year. However, remote monitoring can reduce need for physical diagnoses. These devices can call an ambulance to pickup the patients in case of emergency. The wearable IoT devices used by first responders, can monitor their health and location during emergencies, ensuring their safety in dangerous situations.

Drones: With the introduction of flying drones, a part of city inspection can be done efficiently in real-time by specialized persons remotely. Armed with a high resolution camera, the drones can record and relay live footage to the operator on the ground. Using drones for other similar maintenance activities will be a game changer. The drones will use 5G network to send data to the cloud where data will be processed, and results will be sent to the manager in real-time. The 5G cameras in drones can provide real-time on the scene-data that gives first responder's information they need to make informed decisions.

VII. CONCLUSION

A city that runs more smoothly and has less congestion become more productive and in turn become more economically successful and efficient peak usage times. Implementing smart city, leveraging IoT and connected technology, helps promote economic development, improve infrastructure and environment, enhance transportation systems, and optimize costs of managing public assets. New technology hubs created by smart city IoT deployment may create centers of business and innovation that can create economic activity, commerce, and new jobs.

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