The Evolution of IoT Applications in Smart Homes and Smart Cities: A 2019-2024 Analysis

Goutam Shaw[1], Isika Ghosh[2], Kusum Kumari[3], Himadri Bose[4], Jiya Singh[5], Anurima Majumdar[6], Antara Ghosal[7] , Suparna Biswas[8]

[1-8]Department of Electronics and Communication Engineering
Guru Nanak Institute of Technology, West Bengal, India

ABSTRACT

The Internet of Things has revolutionized the way we interact with our surroundings, particularly in the domain of smart homes and smart cities. This paper provides a detailed analysis of IoT applications in smart homes and smart cities from period 2019-2024. Beginning with an overview of IoT technology and its various applications within smart homes and smart cities.Additionally, it examines the emerging technologies like AI, blockchain to enhance security and functionality. Furthermore, the paper explores the challenges like interoperability,security and privacy concerns and their potential solutions. Finally, it indicates the future research directions and opportunities for upgrading IoT applications in smart homes and smart cities like underwater Kolkata metro to create more sustainable, efficient and livable environments.

1. INTRODUCTION

Smart cities and smart homes are the concept of makingthe lives of people more efficient, comfortable and easy.They are operated by IoT (Internet of Things) technology that make the world more modern, safe and reliable by connecting the physical world with digital technology. They are importantto deal with modern urban challenges like interoperability, safety and security etc. by using IoT technology. Physical implementations involve using of IoT devices such as sensors, actuators, and data analytics platform to gather information from various city components like transportation system, buildings etc.Some examples of smart cities are London, Singapore, Oslo etc. **[1]**. Figure1 shows wide overview of IoT application areas.

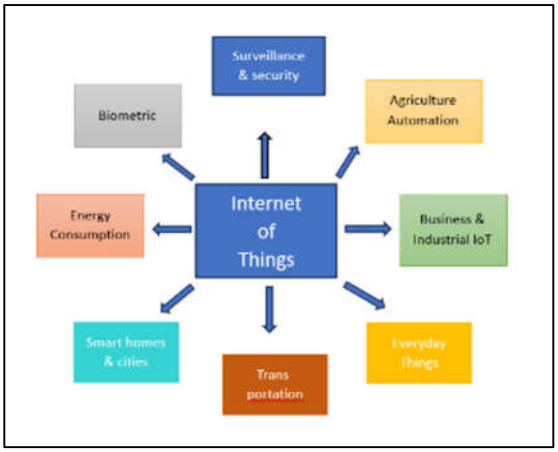

Fig 1. Applications of IoT

From 2019 to 2024, IoT applications have undergone significant evolution across various sectors. In 2019, integration with AI enabled automation in smart homes, while healthcare and transportation saw expanded applications of IoT for remote monitoring and traffic management, respectively. In 2020, IoT played a crucial role in pandemic response and addressing cybersecurityconcerns in smart home devices. The year 2021 witnessed the integration of environmental sensors for pollution monitoring and the expansion of smart grid solutions in urbanareas. In 2022, advancements in connectivity with 5G and enhanced security measures through blockchain integration transformed IoT in smart cities. Finally, in 2023, IoT converged with edge computing for real-time analytics and witnessed advancements in smart transportation systems using V2X communication. These developments reflect a maturation and integration of IoT technologies, paving the way for smarter, more efficient, and resilient cities and homes.In 2024,TBM technology uses advanced

cylindrical machines to excavate dirt and rock to build tunnels while installing tunnel linings. This advanced method is widely used in tunneling in a variety of geological formations, including soft soils, hard rock, and underwater environments such as rivers and oceans. TBM technology offers many advantages over traditional drilling and blasting techniques, including shortening construction schedules, minimizing disruption to ground activities, and improving worker safety.

This paper explores how IoT is changing smart homes and cities from 2019-2024.As the technology is getting advance and urban areas are growing, understanding these changes is very important. By analyzing the changes, trends, case studies the paper provides a valuable insight into the role of IoT in shaping the urban environments, help in decision-making and encourage transformation.

2. EVOLUTION OF IoT APPLICATIONS: YEAR-WISE ANALYSIS

2.1 2023: INTEGRATION WITH EMERGING TECHNOLOGIES

2.1.1 CONVERGENCE OF IOT WITH EDGE COMPUTING FOR REAL-TIME ANALYTICS

Edge computing complements IoT by processing data locally at the point of origin, reducing latency and optimizing bandwidth. This coordination enables real-time decision-making and enhances security. Industries like manufacturing; autonomous vehicles, healthcare, and surveillance leverage this combination extensively. For instance, in manufacturing, edge computing addresses latency and data security challenges by processing data at the source. Autonomous vehicles rely on edge computing for quick data processing, crucial for road safety. In healthcare, edge-enabled sensors enable real-time patient monitoring, aiding remote care. As surveillance systems expand, IoT-edge technology becomes essential for real-time analytics, meeting the demand for quick decision-making in public safety**[2]**.

Fig 2**.** Future market potential of Edge-Enabled IoT [15]

2.1.1 ADVANCEMENTS IN SMART TRANSPORTATION SYSTEMS WITH IOT AND V2X COMMUNICATION

Over the past decade, IoT has transformed various sectors, including transportation, into intelligent platforms with connected vehicles. Connected vehicles, a key component of V2X communication, aim to improve road safety and traffic management. However, the rise in road accidents necessitates advancements in Intelligent Transportation Systems (ITS). V2X communication utilizes wireless technologies like LTE and 5G to exchange information between vehicles and infrastructure. V2X applications include traffic management, road safety, autonomous driving, and infotainment, aiming to optimize traffic flow, ensure safety, and enhance driver experiences. Cellular technologies offer advantages in reducing latency and improving packet delivery, enhancing V2X communication environments**[3]**.

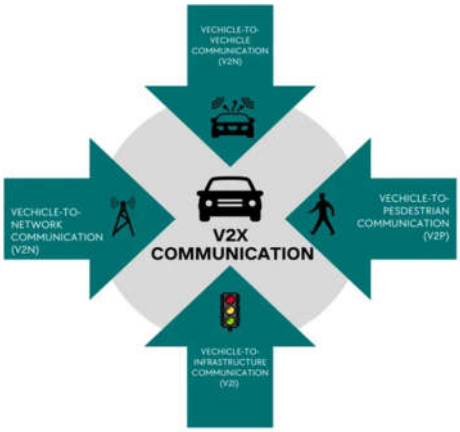

Fig3 Vehicle-to-Everything Communication (V2X) protocol [3]

2.2 2022: Advancements in Connectivity and Security

2.2.1 Adoption of 5G for High-Speed, Low-Latency IoT Connectivity

In 2022, the advent of 5G technology transformed IoT in smart cities, offering rapid, low-latency connectivity crucial for real-time data processing in applications like autonomous vehicles and smart grids. Lower latency ensures immediate responses, vital for healthcare and transportation. 5G's scalability accommodates the expanding IoT device ecosystem, while its reliability and energy efficiency drive innovation, fostering faster, more reliable urban connectivity**[4]**.

Fig 4. IoT enabled 5G use cases

2.2.2 Enhanced Security Measures, Including Blockchain Integration

In 2022, making smart cities safer involves using blockchain technology. Blockchain keeps data secure by storing it across many places, making it hard to tamper with. It also adds layers of protection to devices. With features like hidden proofs, it shares data transparently while keeping it private. Blockchain's design makes it tough for hackers to attack, making smart city systems more secure and trustworthy [5].

2.3 2021: Sustainability and Environmental Focus

2.3.1 Integration of Environmental Sensors for Pollution Monitoring

A low-cost IoT wireless sensor network was developed to monitor air quality in suburban areas. Equipped with various pollutant sensors, the sensor motes create an ESP-NOW network, connecting to a server via Wi-Fi and powered by solar panels. Enhanced by a reliable scheme and a fractional-order Kalman filtering algorithm, it accurately tracks air pollutants. Tested for six months in different conditions, it demonstrated strong correlation with State-run station data and proved effective in estimating dust distributions [6].

2.3.2. Expansion of Smart Grid Solutions in Urban Areas

IoT integration in smart grids addresses power concerns, enabling bi-directional data and power flow, self-healing, and advanced functions like DSM and LF. Real-time monitoring of energy consumption and demand improves efficiency, while standard protocols ensure connectivity. Strategically placed IoT sensors optimize electricity distribution. Successful implementations include Germany's Mannheim project, Lumin platform, Schneider Electric's solar solutions, Cisco's BC Hydro modernization, and Siemens' energy intelligence solutions [7].

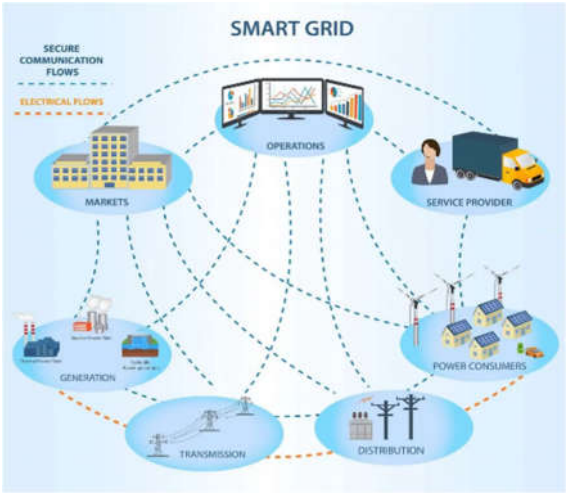

Fig 5. Smart grid secure communication flow[16]

2.4 2020: Resilience and Adaptation

2.4.1. IoT Applications for Pandemic Response in Smart Cities

The COVID-19 pandemic prompted significant financial and technological responses globally. Healthcare IoT (HC-IoT) has been instrumental in prevention, diagnostics, and treatment. Security measures include authentication models and privacy-preserving protocols, utilizing technologies like blockchain. Efforts also target combating DDoS attacks and ensuring data privacy. Emerging tech

such as AI, ML, and edge computing aid pandemic management. Challenges persist in securely integrating these technologies while safeguarding patient privacy and ensuring data reliability [8].

2.4.2. ADDRESSING CYBER SECURITY CONCERNS IN SMART HOME DEVICES

As smart devices become more prevalent in homes, cybersecurity risks increase due to the extensive collection of personal data. Unauthorized data collection by third party compromises user privacy, eroding trust. Manufacturers must prioritize user security through transparent design and ethical practices. Value-sensitive approaches, focusing on user interests, are essential for mitigating risks and empowering users to manage their security and privacy effectively**[9]**.

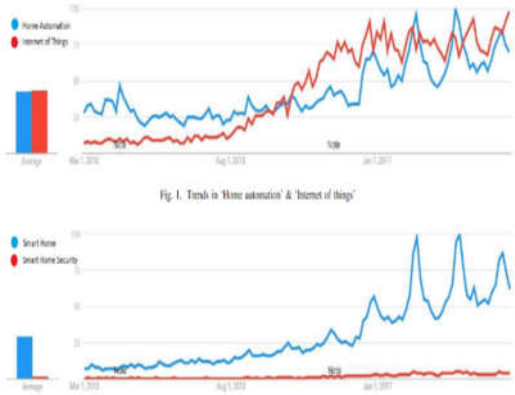

Fig6.Trends in 'Home Automation'&'Internet of Things' and Trends in 'Smart Home' & 'Smart Home Security'[9]

2.5 2019: MATURATION AND INTEGRATION

2.5.1 INTEGRATION OF IOT WITH AI FOR ENHANCED AUTOMATION

The integration of IoT with AI has led to the development of smart homes that can automate various tasks, such as controlling lighting, temperature, and security systems. AI algorithms can analyze data from IoT sensors and devices to optimize energy consumption, improve comfort, and enhance security [10].

2.5.2.EXPANSION OF IOT APPLICATIONS IN HEALTHCARE AND TRANSPORTATION

IoT has significantly impacted healthcare by enabling remote patient monitoring, real-time data collection, and predictive analytics. Wearable devices, such as smartwatches and fitness trackers, can monitor vital signs, track physical activity, and alert healthcare professionals in case of emergencies. IoT sensors can also be used for environmental monitoring in hospitals, ensuring optimal conditions for patient care.IoT has transformed the transportation sector by improving traffic management, public safety, and the overall efficiency of transportation systems. Smart traffic management systems can monitor traffic flow, predict congestion, and optimize routes to reduce travel times. IoT sensors can also be used to monitor the condition of infrastructure, such as bridges and roads, ensuring their safety and longevity [11-12].

3. 2024: IOT APPLICATIONS IN AUTOMATION: ACURRENT SCENERIO ANALYSISWITH INDIA'S 1ST UNDERWATER METRO

The inauguration underwater metro station in Asia finds its home in Kolkata, India, as part of the Kolkata Metro Line 2, also known as the East-West Metro. This pioneering endeavor integrates various cutting-edge technologies, with the Tunnel Boring Machine(TBM)standing out as a corner stone in the project's success.

The underwater segment of the Kolkata Metro Line 2 stretches beneath the Hooghly River, linking the eastern and western sectors of the city. Constructing this underwater tunnel posed numerous engineering challenges, including navigating riverbed conditions, managing water pressure, and addressing environmental considerations.

The TBM technology emerged as a vital solution in this ambitious undertaking. TBMs, colossal machines designed for precision tunnel excavation, were deployed to bore through the riverbed, creating the underwater passage for the metro line. Equipped with rotating cutter heads, these TBMs excavated the tunnel face while simultaneously installing precast concrete segments to form the tunnel lining.

The decision to employ TBMs offered several benefits. Firstly, TBMs significantly expedited the tunneling process, outpacing traditional methods and accelerating project completion. Moreover, TBMs are adept at operating in diverse geological conditions,

adeptly handling the soft riverbed sediments and hard rock layers encountered beneath the Hooghly River.

Beyond expediency, TBMs also contributed to environmental stewardship. By confining the excavation process within the tunnel itself, TBMs minimized disruption to the riverbed and mitigated potential environmental impacts, such as sedimentation and pollution.

The successful integration of TBM technology with other advanced engineering methodologies underscores Kolkata's prowess in urban infrastructure development. This feat represents a remarkable convergence of innovation, engineering excellence, and environmental sustainability **[17].**

Fig 7. East West Metro Tunnel [18]

3. CASE STUDIES AND EXAMPLES

Smart home voice assistants like Amazon Echo and Google Home gained popularity. IoT-based home security systems like Ring doorbell cameras saw massive growth. Meanwhile cities like Barcelona have started smart urban projects for traffic and parking management.Singapore's Smart Nation project focuses on waste management with anIoT-enabled system. Copenhagen used IoT sensors for environmental monitoring, tracking air quality to reduce pollution.New York and Chicago, USA, utilizedsmart displays using city-wide sensing and connectivity to safeguard customers.Padovasmart city provides the financing and infrastructure where street light pole sensors collect public illumination and environmental data.Amsterdam, the Netherlands, utilized systems that increased security and visibility for people. These systems are connected to internet, resulting in greater energy savings**[13]**.Kolkata, India started the first underwater East-West Metro Station.

4. CHALLENGES AND SOLUTIONS

Security and Privacy are the primary concerns in smart cities and smart homes. As a large number of devices are connected to the internet there is a potential risk of harmful attacks, so this is a critical issue as it involves personal information. Therefore, security mechanisms like encryption areneeded with cost-effective strategies.With new emerging applications in smart cities and homes, providing networking to remain connected is a big challenge. There can be another way of networking thatworks on efficient and dynamic routing protocols that are capable of working with stationary as well as devices in motion.Interoperability is a notable challenge in terms of connectivity, communication and integration protocols.Limited battery life and efficiency of IoT devices are challenging issues to be solved. It is necessary to reduce wastage of energy [14].

5. FUTURE DIRECTIONS AND CONCLUSIONS

The future of IoT in smart homes and cities holds exciting possibilities. There are some suggestions that can be made while working with IoT-enabled projects for smart homes and cities.The major research areasare in manufacturing of smart devices, sensors and IoT objects with interoperability, high efficiency, reliability and battery life. Security, trust, privacy, safety and quality of service management of IoT systems are challenging research direction. The area of AI also has scope for potential work.Other areas to work on, are blockchain, power management and energy harvesting solutions, design and communication protocols.

In conclusion, this paper presents a broad coverage of the evolution of IoT in smart home and citiesand shown huge potential for improving convenience, efficiency and sustainability. Number ofchallenges related to privacy, security, interoperability etc. have been discussed for future recommendations. By addressing these challenges, we can achieveeven greatersuccess in thedeployment of smart homes and cities.

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