Metaversalize

www.meta.reapress.com

Metaverse Vol. 1, No. 2 (2024) 62–71.

Paper Type: Original Article

AI-Powered Smart City Infrastructure with Integrated IoT Systems

Aman Kumar Sharma*

School of Computer Science Engineering, KIIT University, Bhubaneswar, India; 22052002@kiit.ac.in.

Citation:

Received: 26 Octobert 2023 *Revised: 24 January* *Accepted: 28 February 2024*	Sharma, A. K. (2024). AI-powered smart city infrastructure with integrated IoT systems. *Metaversalize, 1*(2), 62-71.

Abstract

With the rise of urbanization, cities encounter difficulties in ensuring secure, sustainable, and convenient living conditions. The Internet of Things (IoT) links physical objects through electronics, sensors, software, and communication networks, reshaping the infrastructure of smart cities. By utilizing Artificial Intelligence (AI) to analyze data from IoT devices, new possibilities emerge for designing and managing advanced smart cities. This review examines smart cities, the architecture of IoT, and wireless communication technologies, identifying the most appropriate ones for specific uses. It also investigates AI algorithms and their connection with IoT, emphasizing the potential benefits of combining AI with 5G networks. The article highlights the significant possibilities that arise from the integration of IoT and AI, improving urban living standards, promoting sustainability, and boosting productivity. Additionally, it offers perspectives on the future of smart cities.

Keywords: Smart cities, Internet of things, Artificial intelligence.

1 | Introduction

Cities are complex systems with interconnected citizens, transportation, communication networks, services, businesses, and utilities aimed at improving urban lifestyles. As urban populations grow, city governments face pressure to provide essential services like housing, agriculture, and environmentally friendly buildings. Smart cities require advanced telecommunication and wireless infrastructures to effectively deliver services and connect millions of devices using Machine-to-Machine (M2M) communication, network virtualization, wireless sensor networks, and gateways [1]. *Fig. 1* shows the data rate, power consumption, establishment cost, and coverage range of various communication technologies.

Corresponding Author: 22052002@kiit.ac.in
https://doi.org/10.22105/metaverse.v1i2.61

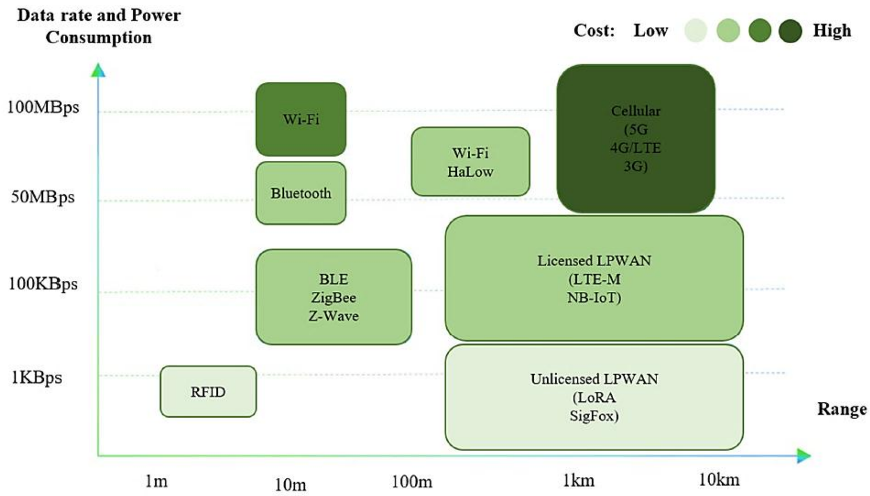

Fig. 1. Comparison of date rate, power consumption, cost, and available communication technologies coverage range.

The Internet of Things (IoT) significantly impacts modern communication by enabling the interaction of everyday objects with microcontrollers, radio modules, and communication protocols [2], [3]. IoT is crucial for smart cities, with governments and private organizations using it in Information and Communication Technologies (ICT) to enhance service quality and reduce costs [4–6]. IoT technologies are vital for developing smart cities, managing large-scale data, and driving sustainable development. By 2030, IoT-enabled devices are expected to exceed 29 billion, highlighting IoT's importance in creating innovative and efficient urban environments. Various strategies and technologies are being implemented to address the complexities of smart city management. IoT devices collect vast amounts of data on temperature, humidity, traffic flow, energy consumption, and air quality, enhancing city management and residents' living standards. Artificial Intelligence (AI) uses machine learning to analyze this data, identifying patterns and trends that are difficult for humans to detect [7], [8]. This is crucial for predictive maintenance, ensuring infrastructure remains in good condition. AI also supports smart water supply, energy management, waste management, and reducing congestion and pollution. Around 30% of smart city applications now integrate AI, a trend expected to grow by 2025. While AI and IoT integration offers significant benefits, it raises concerns about privacy, data security, and biases, necessitating strong ethical frameworks (*Fig. 2*).

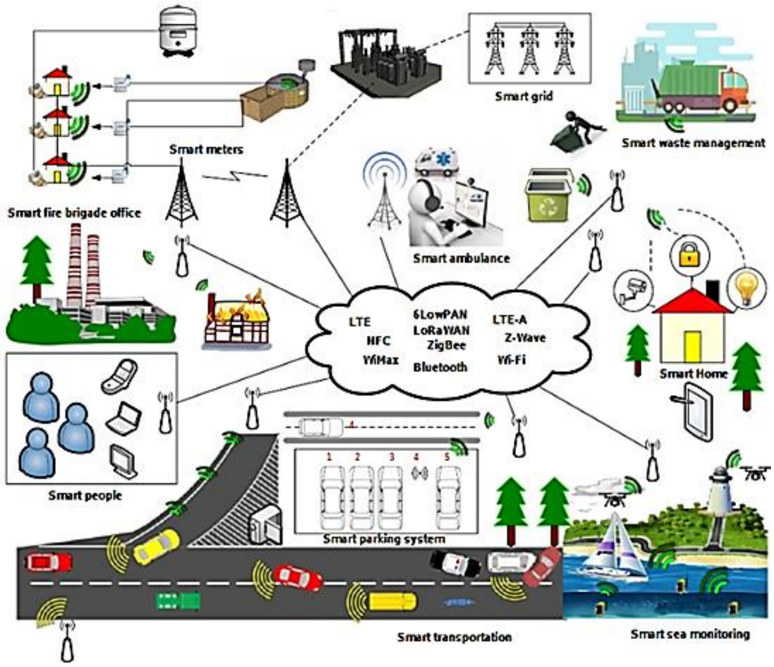

Fig. 2. Available communication technologies in various applications for smart cities.

The article explores the integration of IoT and AI technologies in smart cities, focusing on how these technologies enhance communication and data exchange among various city services. It emphasizes the importance of robust networking infrastructures for efficient operation. While previous reviews have covered aspects like big data and network security, this article uniquely addresses the combined impact of IoT and AI on smart cities. It discusses how IoT enables device communication, making them integral to smart city functions, and how AI can analyze the vast data from IoT sensors to improve city management and residents' quality of life. The article is structured to introduce smart cities, explain the research methodology, and define key concepts and components.

I. IoT technologies: Discusses sensors, networks, and data analytics essential for smart cities.

II. AI algorithms: Explores AI algorithms and their potential impact on urban life.

III. Future trends: Examines trends like 5G integration and AI applications in smart cities.

IV. Conclusions: This section provides conclusions and future prospects for smart city development, emphasizing the benefits for residents, governments, and businesses.

2 | Methodology

The field of smart cities is rapidly evolving, making it ideal for an integrative literature review. To achieve this, relevant academic papers were meticulously selected and screened. Two primary databases, Google Scholar and PubMed, were used to gather peer-reviewed articles from reputable publishers, focusing on high-quality publications. The references listed in these papers identified additional resources to expand the analysis.

The selection of academic papers was based on their relevance to the investigated issues, ensuring a comprehensive analysis that included both empirical and qualitative studies. Only studies demonstrating consistent findings supporting the advancement of smart city initiatives were included, while those with divergent or inconclusive results were excluded.

From 2010 onwards, PubMed was specifically used to search for keywords such as "smart city," "smart city and IoT," and "smart city, IoT, and AI." The number of published articles was gathered and presented in *Fig. 3*, showing that AI, IoT, and smart cities gained significant attention after 2015, highlighting both challenges and opportunities in the smart city context.

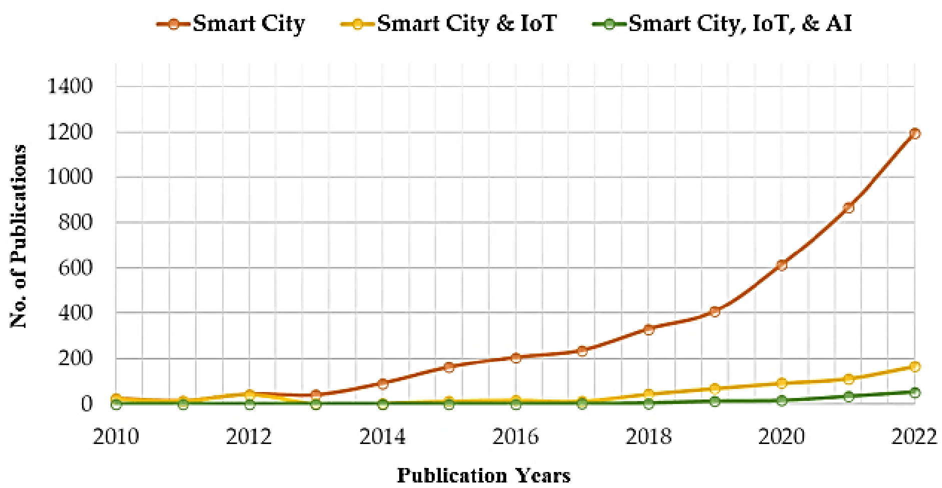

Fig. 3. Trends in academic publications on "smart city", "smart city and internet of things", and "smart city, internet of things, and artificial intelligence" since 2010. The graph presents the number of published articles gathered from a search conducted on the PubMed search engine.

Following the analysis of academic papers, supplementary sources like governmental reports, reputable newspaper articles, and websites were searched on Google to reinforce the conclusions. *Fig. 4* provides an overview of the methodology for integrating IoT and AI applications in smart cities.

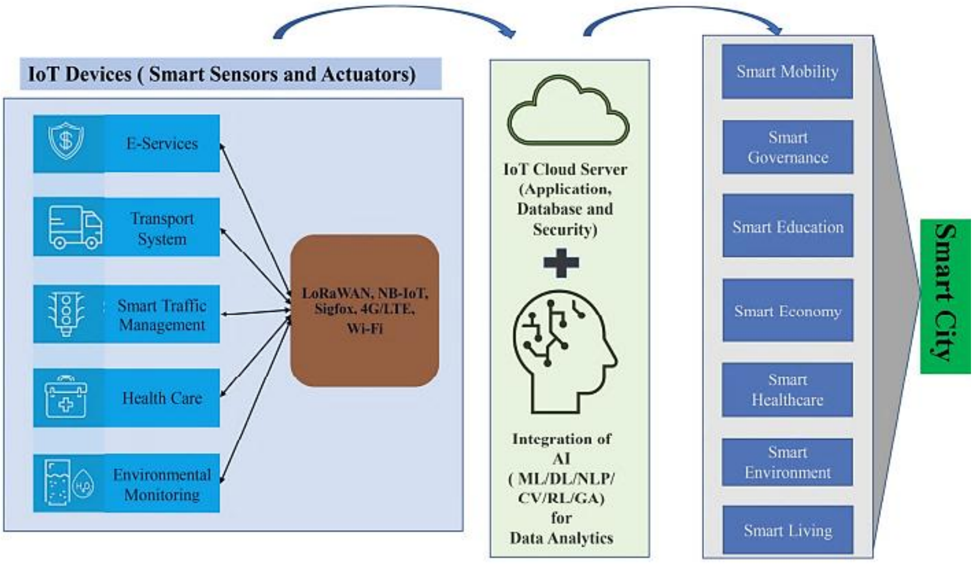

Fig. 4. An overview of the methodology for introducing applications in a smart city through integrating internet of things and artificial intelligence.

3 | The Smart City Paradigm

The term "smart city" has various definitions and is often used interchangeably with terms like "intelligent city" and "digital city." This ambiguity arises because there is no universally accepted definition. Smart city concepts emerged to address urbanization challenges and promote sustainable development by integrating IoT, AI, and big data analytics. These technologies aim to improve urban services, reduce resource consumption, and enhance residents' quality of life.

Technological advancements enable modern smart cities to collect and analyze data from various applications, such as smart agriculture, healthcare, and traffic, to make informed decisions that improve living standards. The rapid development of IoT, cloud computing, and AI is crucial for enhancing urban facilities' performance and interactivity, reducing management costs, and improving skills.

There are two main approaches to defining smart cities. The first focuses on a single urban feature, such as technology or ecology, without considering the interconnectedness of all urban components. The second approach views the smart city as a comprehensive system that integrates economic, technological, and social factors to ensure urban stability and sustainability. This holistic approach emphasizes considering all urban characteristics to address modern cities' challenges effectively.

4 | The Architecture of Internet of Things-Enabled Smart City

Technological advancements could introduce millions of intelligent sensors to city infrastructures, operating with the efficiency of 1000 IoT devices. Effective data management from these sensors is crucial for the smooth operation of smart city ecosystems. Classifying applications is essential to establishing a solid foundation for smart cities and evaluating areas like governance, economy, and healthcare within the smart city context.

Smart cities rely on advanced communication technologies and IoT infrastructure, requiring specific communication systems and architecture. This infrastructure facilitates information exchange among urban stakeholders, regardless of the application. Communication is key for transmitting data between sensors and devices. Three common communication patterns are used: 1) cellular mobile networks, 2) IoT-dedicated cellular networks, and 3) multi-tier networks. *Fig. 5* illustrates these architectures. Proper classification based on application type is necessary to measure the smartness of various urban entities.

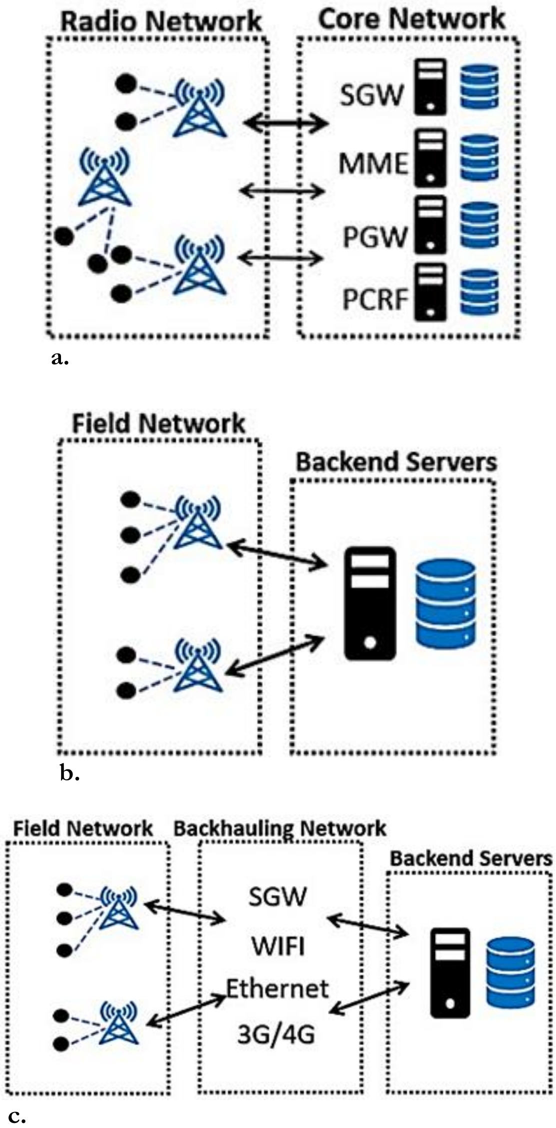

Fig. 5. Architectures for supporting the machine-to-machine communications in smart cities; a. cellular architecture, b. internet of things dedicated cellular architecture, c. multi-tier architecture.

The document outlines the key architectural components and communication technologies essential for smart cities:

I. Architectural components: Four main components are highlighted: 1) data sensing/actuating, 2) networking and communication, 3) vital components, and 4) cloud/fog computing.

II. Perception or sensing layers: This section discusses physical devices like sensors and actuators that interact with the physical world and measure various quantities such as humidity, temperature, and environmental factors.

III. Networking and communication: Various communication protocols connect devices in smart cities. Short-range protocols like Wi-Fi, ZigBee, and Z-Wave are suitable for limited coverage areas [9]. In contrast, long-range protocols like LoRaWAN, NB-IoT, Sigfox, and LTE are better for broader applications [10]. Each protocol has unique features that suit specific smart city applications.

IV. Evolutions of GSM and LTE: The document also touches on GSM/GPRS and LTE advancements for improving M2M communication efficiency.

Understanding these components and communication protocols helps create efficient, sustainable, livable smart cities by integrating IoT-enabled devices and AI algorithms.

The document discusses the evolution of GSM and LTE technologies to enhance M2M communication efficiency in smart cities:

I. GSM/GPRS enhancements: Efforts focus on improving uplink capacity, extending coverage, and reducing power consumption and complexity of M2M devices. Techniques like Extended Coverage GSM (EC-GSM) use FDMA and CDMA to support more IoT devices on the same frequency band [11].

II. Narrowband Cellular IoT (NB-IoT): This approach uses narrowband channels for downlink and uplink, employing OFDMA for downlink and FDMA for uplink to meet device-specific requirements.

III. LTE evolutions: LTE Rel-11 and Rel-13 focus on handling many IoT devices with reduced capabilities, improving power saving, and enhancing narrowband transmission for M2M communication. Small-cell technology in LTE augments bandwidth and supports low-power, cost-effective devices, making it suitable for various smart city applications.

These advancements aim to create efficient, resilient, low-power communication networks essential for smart city infrastructure.

Weightless protocol

The Weightless system, managed by the Weightless Special Interest Group (SIG), uses FDMA for uplink transmissions to allow concurrent transmissions and prevent interference. The system's architecture includes the physical layer (uplink and downlink) and the data link layer, which has three sub-layers: 1) baseband, 2) lower link layer, and 3) upper link layer. The Radio Resource Manager (RRM) handles radio resource management at the MAC layer, supporting transmission acknowledgment, fragmentation, and multicast.

LoRaWAN

The LoRa alliance developed LoRaWAN to connect low-power IoT devices over large areas, using different ISM bands per regional regulations [12]. The physical layer uses Chirp Spread Spectrum (CSS) modulation for two-way communication. LoRaWAN devices are categorized into three classes:

I. Class A: low power, limited downlink channels.

II. Class B: similar to Class A but with extra time windows.

III. Class C: continuous receiving windows, support.

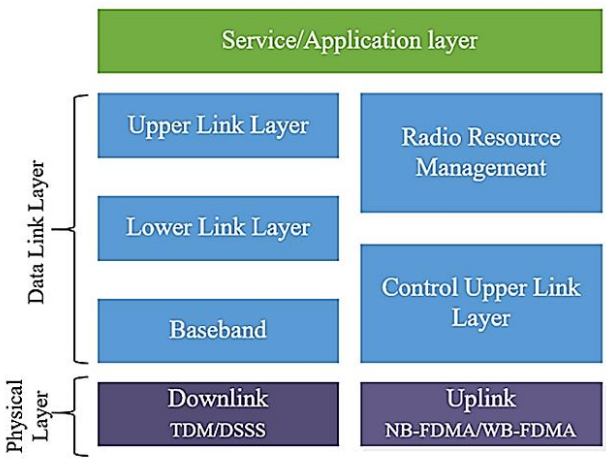

Fig. 6. The reference architecture for the weightless system.

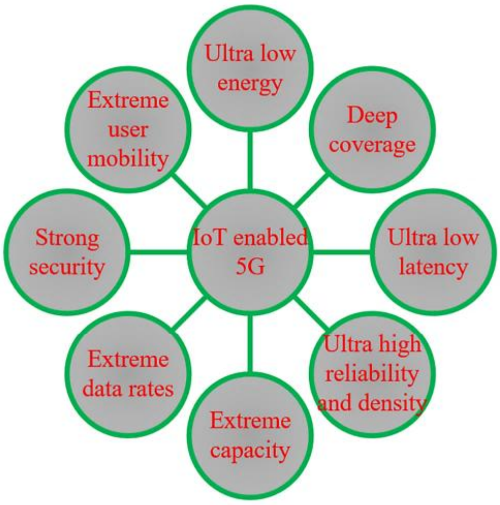

Fig. 7. Probable characteristics of internet of things-enabled 5G networks that would be useful for smart cities.

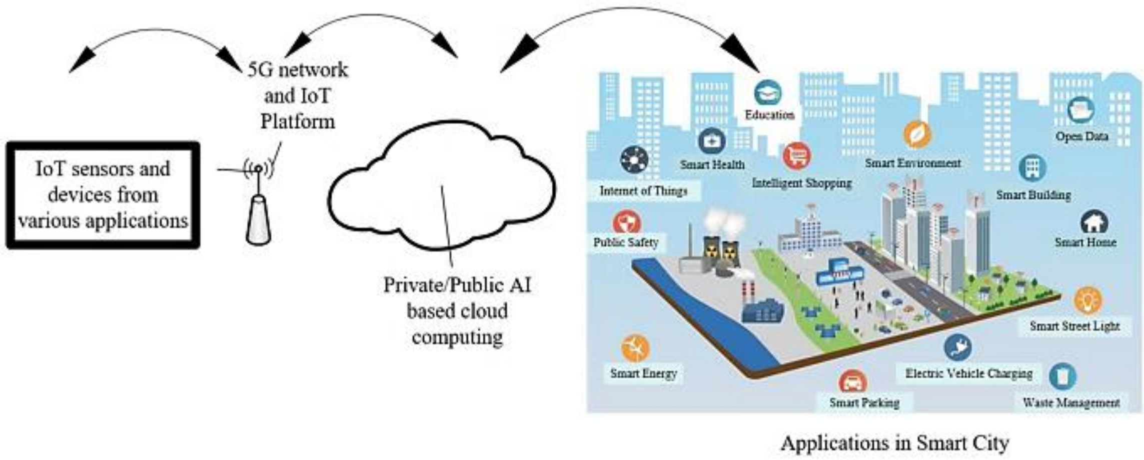

Fig. 8. Illustration of the combination of internet of things, 5G and artificial intelligence, which would be the integral components of a futuristic smart city.

Table 1. A comparison of different short-range communication standards.

		Spectrum	Channel Width	Tx Rate Uplink	Tx Rate Downlink	Packet Size	Max Range (km)	Tx Power	Standard (If Any)
Sigfox		868–902 MHz	100 Hz	≤100 bps	256 bday	≤12 bytes	10–50	10 μW–100 mW	Available
LoRaWAN	EU	863–870 MHz & 433 MHz	125–250 kHz	250–50 bps	250 bps–50 kbps	≤222 bytes	2–15	14 dBm	Available
	US	902–928 MHz	125–500 kHz	980 bps–21.9 kbps	980 bps–21.9 kbps	≤222 bytes		20 dBm	Available
Weightless	W	470–790 MHz TV white spaces	6–8 MHz	250 bps–50 kbps	2.5 kbps–16 Mbps	≥10 bytes	5	17 dBm	Available

Table 1. Continued.

		Spectrum	Channel Width	Tx Rate Uplink	Tx Rate Downlink	Packet Size	Max Range (km)	Tx Power	Standard (If Any)
	N	Sub GHz (ISM)	200 Hz	250 bps	None	≤20 bytes	3	17 dBm	Available
	P	Sub GHz (ISM)	12.5 kHz	200 bps–100 kbps	200 bytes–100 kbps	≥10 bytes	2	17 dBm	Available
Ingenu		2450 MHz	1 MHz	624 kbps	156 kbps	6 bytes–10 k bytes	100	20 dBm	Available

Table 2. A comparison of different short-range communication standards.

		Spectrum	Channel Width	Tx Rate Uplink	Tx Rate Downlink	Packet Size	Max Range (km)	Tx Power	Standard (If Any)
Sigfox		868–902 MHz	100 Hz	≤100 bps	256 bday	≤12 bytes	10–50	10 µW–100 mW	Available
LoRaWAN	EU	863–870 MHz & 433 MHz	125–250 kHz	250–50 bps	250 bps–50 kbps	≤222 bytes	2–15	14 dBm	Available
	US	902–928 MHz	125–500 kHz	980 bps–21.9 kbps	980 bps–21.9 kbps	≤222 bytes		20 dBm	Available
Weightless	W	470–790 MHz TV white spaces	6–8 MHz	250 bps–50 kbps	2.5 kbps–16 Mbps	≥10 bytes	5	17 dBm	Available
	N	Sub GHz (ISM)	200 Hz	250 bps	None	≤20 bytes	3	17 dBm	Available
	P	Sub GHz (ISM)	12.5 kHz	200 bps–100 kbps	200 bytes–100 kbps	≥10 bytes	2	17 dBm	Available
Ingenu		2450 MHz	1 MHz	624 kbps	156 kbps	6 bytes–10 k bytes	100	20 dBm	Available

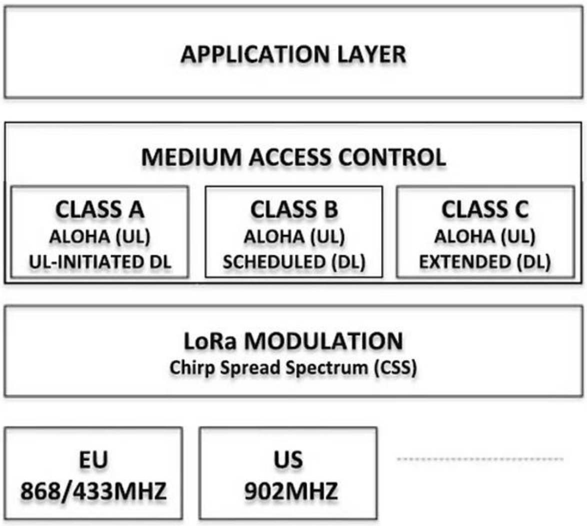

Fig. 9. The reference architecture of LoRaWAN.

5 | Conclusion

Integrating IoT and AI in smart city infrastructure presents transformative opportunities for urban development. By leveraging AI-driven analytics and IoT-enabled communication networks, cities can enhance sustainability, efficiency, and overall quality of life for residents. The combination of smart sensors, machine learning algorithms, and 5G networks allows for real-time monitoring, predictive maintenance, and automated decision-making in essential services such as transportation, energy management, and waste disposal.

Despite the numerous benefits, challenges such as data privacy, security, and ethical considerations must be addressed to ensure responsible deployment. Future advancements in AI, IoT, and wireless communication will continue to shape the evolution of smart cities, making them more interconnected and intelligent. Policymakers, researchers, and technology developers must collaborate to establish regulatory frameworks that promote innovation while safeguarding citizens' rights and security.

This study underscores the potential of AI-powered smart city systems in fostering sustainable urban development. With continued research and investment, smart cities will become more resilient, adaptive, and capable of meeting the needs of future generations.

Acknowledgments

We want to express our sincere gratitude to all the researchers, engineers, and professionals who have contributed to the advancements in IoT and AI technologies. Their innovative work and dedication have significantly propelled the development of smart cities, making urban environments more efficient, sustainable, and livable. Special thanks to the institutions and organizations that have supported this research, providing the necessary resources and platforms for collaboration. We also appreciate the valuable insights and feedback from peer reviewers, which have greatly enhanced the quality of this work. Lastly, we acknowledge the continuous support from our families and colleagues, whose encouragement has been instrumental in completing this study.

Funding

KIIT university supported this research; the funding provided by KIIT university was instrumental in facilitating the research and development of AI-powered smart city infrastructure with integrated IoT systems. We also acknowledge the support from KIIT university, which provided additional resources and infrastructure necessary for this study. The collaboration between KISS and KIIT has been crucial in advancing our understanding and implementation of smart city technologies.

Data Availability

The data that support this study's findings are available from the Aman Kumar Sharma upon reasonable request. The datasets generated and analyzed during the current study are not publicly available due to privacy or ethical restrictions but are available from the Aman Kumar Sharma upon reasonable request. Additionally, some data may be subject to third-party restrictions and require permission from the respective data holders.

Conflicts of Interest

The author declare that there are no conflicts of interest regarding the publication of this paper. The research was conducted independently, and no financial or personal relationships influenced the outcomes of this study. All funding sources and affiliations are transparently disclosed, ensuring the integrity and impartiality of the research findings.

This statement ensures transparency and maintains the credibility of the research by declaring that the authors have no conflicting interests that could have influenced the study's results.

References

[1] Abadi, M. J., & Khalaj, B. H. (2022). Connectivity through wireless communications and sensors. In *Industry 4.0 vision for energy and materials: Enabling technologies and case studies* (pp. 3–58). Wiley online library. https://doi.org/10.1002/9781119695868.ch1

[2] Lombardi, M., Pascale, F., & Santaniello, D. (2021). Internet of things: A general overview between architectures, protocols and applications. *Information*, *12*(2), 87. https://doi.org/10.3390/info12020087

[3] Bakar, K. B. A., Zuhra, F. T., Isyaku, B., & Sulaiman, S. B. (2023). A review on the immediate advancement of the internet of things in wireless telecommunications. *IEEE access*, *11*, 21020–21048. https://doi.org/10.1109/ACCESS.2023.3250466

[4] Tcholtchev, N., & Schieferdecker, I. (2021). Sustainable and reliable information and communication technology for resilient smart cities. *Smart cities*, *4*(1), 156–176. https://doi.org/10.3390/smartcities4010009

[5] Mohapatra, H., & Rath, A. K. (2021). An IoT based efficient multi-objective real-time smart parking system. *International journal of sensor networks*, *37*(4), 219–232. https://doi.org/10.1504/IJSNET.2021.119483

[6] Pratap, A., Nayan, H., Panda, P., & Mohapatra, H. (2024). Emerging technologies and trends in the future of smart cities and IoT: A review. *Journal of network security computer networks*, *10*(2), 28–38. https://matjournals.net/engineering/index.php/JONSCN/article/view/606

[7] Mazhar, T., Irfan, H. M., Haq, I., Ullah, I., Ashraf, M., Shloul, T. Al, … ., & Elkamchouchi, D. H. (2023). Analysis of challenges and solutions of IoT in smart grids using AI and machine learning techniques: A review. *Electronics*, *12*(1), 242. https://doi.org/10.3390/electronics12010242

[8] Mahmood, M. R., Matin, M. A., Sarigiannidis, P., & Goudos, S. K. (2022). A comprehensive review on artificial intelligence/machine learning algorithms for empowering the future IoT toward 6G era. *IEEE access*, *10*, 87535–87562. https://doi.org/10.1109/ACCESS.2022.3199689

[9] Senthilkumar, S. P., & Subramani, B. (2023). Internet of things in low-power wide area network and short range network: A review. *I-manager's journal on computer science*, *10*(4), 33. https://doi.org/10.26634/jcom.10.4.19273

[10] Kadusic, E., Ruland, C., Hadzajlic, N., & Zivic, N. (2022). The factors for choosing among NB-IoT, lorawan, and sigfox radio communication technologies for iot networking. *2022 international conference on connected systems & intelligence (CSI)* (pp. 1–5). IEEE. https://doi.org/10.1109/CSI54720.2022.9923999

[11] Riza, N. A., & Mazhar, M. A. (2021). Triple coding empowered FDMA-CDMA mode high-security CAOS camera. *Applied optics*, *60*(26), 8154–8163. https://doi.org/10.1364/AO.434322

[12] Suomi, H. (2024). *Wireless connection technologies for iot devices in long range, low-power networks*. [Thesis]. https://urn.fi/URN:NBN:fi:amk-2024051311130