6G-DRIVEN WIRELESS COMMUNICATION BASED SMART CITY MODEL USING ESP-NOW AND DISTRIBUTED ANTENNA SYSTEMS (DAS) FOR EFFICIENT COMMUNICATION AND NARROWBAND SENSING

***Project Reference No.:** 48S_BE_1925*

College : East West Institute Of Technolog, Bengaluru
Branch : Department Of Electronics And Communication Engineering
Guide(S) : Mrs. Hema C
Student(S): Ms. Chinmayi B S
Mr. Amit Kumar
Mr. Hemanth Gowda S V
Ms. Vinutha C

Keywords:

Unified Automation System, 6G Ultra-High-Speed Connectivity, Multi-Environment Smart Integration, Real-Time Monitoring & Control, Distributed Antenna System (DAS), Sustainable Development

Introduction:

The future of urban development lies in smart, hyper-connected ecosystems — and at the heart of this transformation is the convergence of 6G wireless communication, Distributed Antenna Systems (DAS), and low-power IoT frameworks. The project titled "6G-Driven Wireless Communication Based Smart City Model Using ESP-NOW and Distributed Antenna Systems (DAS) for Efficient Communication and Narrowband Sensing" presents a cutting-edge approach to building intelligent, responsive, and sustainable urban environments.

Harnessing the unparalleled speed, ultra-low latency, and massive device connectivity of 6G networks, the model ensures real-time, reliable communication between heterogeneous systems across the city. The integration of DAS extends network coverage across complex terrains, buildings, and dense cityscapes, eliminating dead zones and ensuring seamless connectivity. Complementing this infrastructure, the ESP-NOW protocol empowers direct, fast, and power-efficient peer-to-peer communication among IoT devices, reducing dependency on external networks and enhancing system resilience.

This smart city model incorporates a network of narrowband sensors and ESP32 microcontrollers deployed across key urban sectors—homes, offices, transportation networks, energy grids, and public safety systems. These sensors capture critical real-time data such as air quality, traffic density, energy consumption, infrastructure health, and safety indicators. The collected data is processed at the edge for instant automation responses, while the central control unit (Raspberry Pi with DAS support) manages cross-environment coordination, data aggregation, and intelligent decision-making.

By uniting advanced communication protocols with intelligent automation, this model achieves not only efficient resource management and operational excellence but also aligns with the vision of sustainable urban living. It promotes energy efficiency, proactive disaster management, smart mobility, and environmental monitoring, paving the way for future-ready, adaptive smart cities. The project stands as a scalable blueprint, showcasing how 6G-powered IoT ecosystems can transform the way cities operate — smarter, faster, and greener.

Objectives:

- To design an integrated smart city model leveraging 6G communication, Distributed Antenna Systems (DAS), and ESP-NOW protocol for efficient, real-time data exchange and automation across multiple urban environments.
- To deploy ESP32 microcontrollers and narrowband sensors across diversified sectors such as home, office, agriculture, energy, and transportation for real-time environmental monitoring and responsive automation.
- To process and manage data at the edge using Raspberry Pi as the central base station, enabling immediate decision-making and cross-environment coordination with ultra-low latency

- To demonstrate efficient and reliable communication between IoT nodes and the base station using ESP-NOW protocol and DAS infrastructure, ensuring seamless data flow, energy efficiency, and enhanced system resilience in smart city applications.

Methodology:

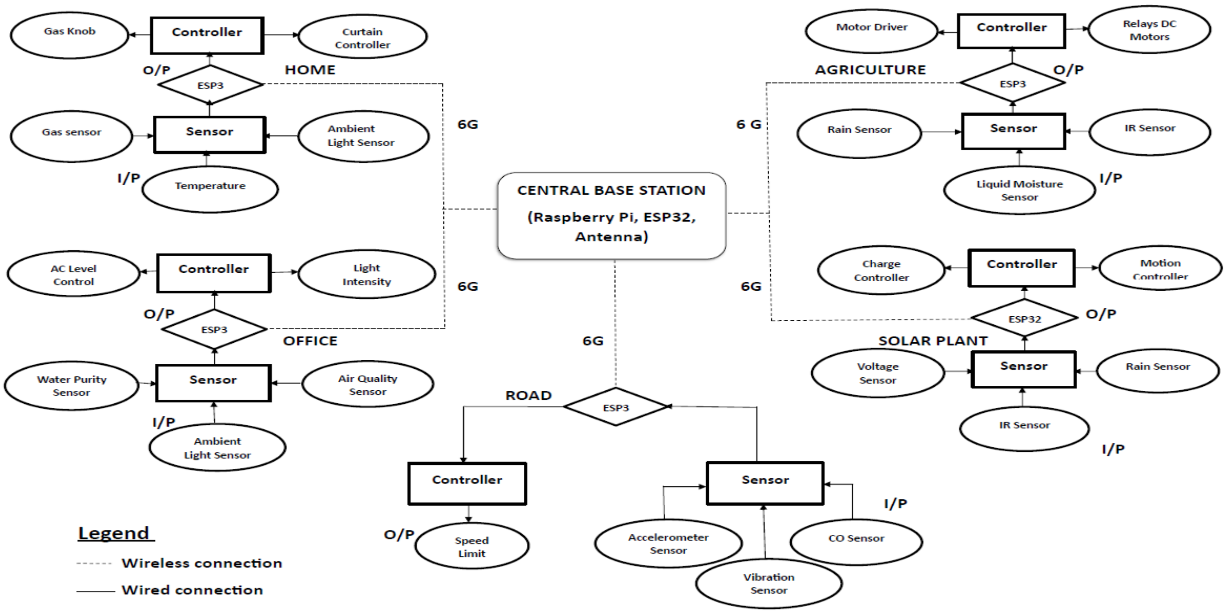

Figure 1: Block diagram of 6g vision: next gen iot and edge automation model developed by using DAS

As illustrated in Figure 1: Block Diagram of 6G Vision: Next-Gen IoT and Edge Automation Model Developed by Using DAS, involves a structured and multi-layered approach to building a fully functional smart city prototype. The system begins with a Centralized Base Station Setup, where a Raspberry Pi functions as the primary control unit. Connected with ESP32 microcontrollers and an external antenna, the base station aggregates real-time data from various environment-specific nodes and processes it to issue appropriate control commands.

The project includes the development of environment-specific modules designed to perform real-time monitoring and automation. In the Home Automation system, sensors like gas detectors and ambient light sensors are deployed to detect leaks and adjust appliances such as curtains, lighting, and ventilation for safety and comfort. The Office Automation module employs air quality sensors, water purity sensors, and light sensors to ensure a healthy and energy-efficient workspace. For Agriculture Automation, rain and soil moisture sensors combined with IR sensors automate irrigation using motor drivers, promoting optimal water usage and crop health. The Solar Plant Automation module integrates solar panel voltage sensors, rain detectors, and IR sensors to adjust panel alignment and supply renewable energy to support agricultural operations. In the Road Safety and Monitoring system, CO sensors, vibration sensors, and accelerometers monitor environmental conditions and vehicle safety, triggering real-time alerts and controlling ignition systems when necessary.

Wireless communication within the system is handled through the ESP-NOW protocol, enabling direct, fast, and low-power communication between ESP32 nodes and the central base station, eliminating dependence on internet connectivity. Additionally, a Distributed Antenna System (DAS) extends robust network coverage, eliminates dead zones, and ensures reliable data transmission across all environments.

Data processing is conducted at the edge using the Raspberry Pi, where automation logic immediately executes control actions based on the sensor inputs. Notably, cross-environment operations are implemented—for example, solar energy generated in the solar plant directly powers irrigation in the agriculture module, enhancing overall system efficiency.

The system incorporates a monitoring and feedback mechanism that constantly analyses sensor data and makes dynamic adjustments to maintain optimal performance and energy efficiency. Finally, the model undergoes testing and validation under various conditions to assess latency, accuracy, and reliability. Each environment is tested for real-time responsiveness, ensuring that the smart city framework operates effectively and is scalable for future urban deployments.

Result and Conclusion:

The developed smart city model, empowered by 6G technology, successfully demonstrated seamless wireless communication and real-time automation across multiple interconnected environments. By integrating Distributed Antenna Systems (DAS) and ESP-NOW protocol, the system ensured fast, low-latency data exchange between the home, office, agriculture, solar, and road modules. Various sensors deployed in each environment collected real-time data, which was swiftly processed to trigger immediate and intelligent responses for safety, energy efficiency, and operational optimization. Home and office environments responded promptly to critical conditions, performing actions such as gas leak detection, air purification, climate regulation, and smart lighting adjustments to enhance safety and comfort.

The agriculture and solar environments were effectively integrated, with solar energy dynamically powering smart irrigation systems, guided by real-time insights from soil moisture and sunlight intensity sensors. The road environment featured advanced monitoring of vehicle dynamics, vibration levels, and air quality, ensuring rapid hazard detection and enabling proactive safety measures. Centralized coordination through the base station, equipped with edge computing capabilities and AI algorithms, enabled intelligent decision-making and predictive maintenance across all environments, reducing energy consumption and enhancing system resilience.

In conclusion, this project successfully showcases how the convergence of 6G communication, DAS, and ESP-NOW can revolutionize urban automation and smart city infrastructure. The model validates the potential of high-speed, ultra-low latency networks to enable real-time, cross-environment coordination and intelligent automation. By optimizing renewable energy usage, improving public safety, and ensuring energy-efficient operation, the system represents a scalable, adaptable, and future-ready solution. It paves the way for the next generation of smart cities, offering a sustainable approach to urban living powered by advanced technologies.

Project Outcome & Industry Relevance:

The project delivers a practical demonstration of how 6G communication, Distributed Antenna Systems (DAS), and ESP-NOW protocol can be effectively integrated to build a highly responsive and energy-efficient smart city infrastructure. By enabling real-time monitoring and automation across critical environments such as homes, offices, agriculture, solar plants, and transportation systems, the model addresses the growing need for smarter urban management. The cross-environment collaboration, like using solar power to drive automated irrigation, showcases sustainable energy utilization and resource optimization. Industries such as smart agriculture, renewable energy, smart mobility, and urban infrastructure management can adopt this framework to improve operational efficiency, safety, and sustainability. The model’s use of edge computing and AI for predictive maintenance and intelligent decision-making aligns with industry trends towards decentralization and automation. Furthermore, the system's scalability and adaptability make it relevant for future smart cities, where billions of IoT devices will require fast, secure, and reliable communication. This project thus contributes meaningfully to advancing IoT-driven urban ecosystems and offers a strong foundation for industrial applications aiming for digital transformation and sustainable development.

Working Model vs. Simulation/Study:

This project involved the development of a physical working model that integrates 6G communication, Distributed Antenna Systems (DAS), and ESP-NOW protocol. The model demonstrated real-time data collection, processing, and automation across multiple environments, including home, office, agriculture, solar, and road systems. Through the use of sensors and actuators, the model showcased practical applications like gas leak detection, solar-powered irrigation, and traffic monitoring. Unlike a purely theoretical study or simulation, this project provided a tangible demonstration of how these technologies can function together in a real-world scenario, with hardware components such as ESP32 microcontrollers, Raspberry Pi, and various environmental sensors playing key roles in the execution.

Project Outcomes and Learnings:

The key outcomes of this project include the successful integration of 6G communication, Distributed Antenna Systems (DAS), and ESP-NOW protocol to develop a responsive and energy-efficient smart city model. The system demonstrated the ability to manage and automate diverse environments, such as homes, offices, agriculture, solar plants, and roads, by collecting and processing real-time data for immediate actions.

From the process of designing and implementing the project, I learned how to integrate multiple technologies and components effectively, such as microcontrollers, sensors, edge computing, and AI for intelligent decision-making. The project helped me understand the complexities involved in real-time communication and data processing in a multi-environment setup, as well as the importance of low-latency systems in automation. Furthermore, I gained practical insights into sustainable energy management, including how solar energy can be optimized to drive automation systems, particularly in agriculture.

The experience of analyzing the model helped me realize the potential of 6G technology in shaping the future of smart cities, and the challenges associated with building scalable, resilient systems that can handle a large number of interconnected devices. I also gained valuable hands-on experience in system integration, testing, and troubleshooting, which enhanced my problem-solving skills and understanding of IoT and automation systems in real-world applications.

Future Scope:

This project lays the foundation for the future of smart cities, powered by advanced technologies such as 6G communication, Distributed Antenna Systems (DAS), and ESP-NOW protocol. In the future, this model can be expanded to support larger urban environments, integrating additional sectors like healthcare, education, waste management, and emergency services to make cities smarter, safer, and more efficient. Further research can focus on enhancing AI algorithms for predictive analytics and machine learning to improve the system's decision-making capabilities, enabling even more precise automation in critical areas like disaster management and public safety. The integration of 5G and 6G networks with autonomous vehicles and smart transportation systems can lead to safer and more efficient traffic management. Another area for future development involves the sustainability of energy use, where further research could explore integrating more renewable energy sources, such as wind and hydroelectric systems, into the model, reducing reliance on the power grid. The energy optimization algorithms could be refined to predict and adjust energy consumption in real time. Moreover, enhanced cybersecurity measures should be a key area for research, ensuring the security of data communication and IoT devices in future smart city networks. Research into edge-to-cloud integration could also provide a more robust data management system, enabling real-time processing at the edge and more comprehensive cloud-based analytics.

Finally, as smart cities continue to evolve, the exploration of collaborative networks and interoperability between different systems will play a significant role in creating a unified urban infrastructure. This project could pave the way for the future of autonomous and self-healing cities, where real-time automation, data-driven decisions, and sustainability converge to form a more efficient urban ecosystem.