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Article

Performance Evaluation and Optimization of FANET-IoT-IoV Interactions in 6G-enabled Smart City Applications

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Abstract: In the wake of rapid urbanization and technological advancements, the emergence of 6G-enabled smart city applications presents unprecedented opportunities to revolutionize urban living, mobility, and sustainability. Central to the realization of smart city visions is the seamless integration and coordination of diverse communication systems, including Flying Ad Hoc Networks (FANETs), Internet of Things (IoT), and Internet of Vehicles (IoV). These interconnected systems hold the potential to enable real-time monitoring, data-driven decision-making, and proactive management of urban infrastructure and services. However, the dynamic nature of smart city environments, coupled with the heterogeneity and resource constraints of FANETs, IoT devices, and connected vehicles, pose significant challenges in ensuring reliable and efficient communication. This research endeavors to address these challenges by focusing on the performance evaluation and optimization of FANET-IoT-IoV interactions within the context of 6G-enabled smart city applications. By systematically evaluating the performance metrics, identifying optimization opportunities, and developing novel methodologies, this research paves the way for the development of robust, scalable, and resilient communication infrastructures that can underpin the future of smart urban environments.

Keywords: FANETs; IoT; IoV; 6G; Smart Cities; Performance Evaluation; Intelligent Networks
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1 Introduction

The rapid evolution of wireless communication technologies, artificial intelligence (AI), and cyber-physical systems is transforming conventional urban infrastructures into intelligent, connected, and autonomous smart cities. Emerging applications such as autonomous transportation, intelligent traffic management, environmental monitoring, public safety, precision logistics, and emergency response require seamless cooperation among heterogeneous communication networks capable of supporting ultra-reliable, low-latency, and high-capacity data exchange [1–5]. In this context, sixth-generation (6G) communication networks are expected to provide a unified communication platform by integrating ultra-high data rates, intelligent edge computing, native AI, integrated sensing and communication (ISAC), and massive machine-type connectivity, thereby enabling next-generation smart city services beyond the capabilities of current 5G systems [6–9].

Among the key enabling technologies of future smart cities are the IoT, IoV, and FANETs. IoT enables large-scale sensing and monitoring through interconnected devices deployed across urban environments [4, 10], while IoV facilitates intelligent vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and vehicle-to-everything (V2X) communications to improve transportation safety and efficiency [2, 11]. FANETs extend network coverage through unmanned aerial vehicles (UAVs) that function as aerial sensing platforms, communication relays, and mobile edge nodes [12–15]. The integration of these three paradigms creates a highly dynamic and heterogeneous communication ecosystem in which aerial, terrestrial, and sensing networks collaboratively exchange information to support real-time decision-making in smart city environments.

Despite their significant potential, integrating FANETs, IoT, and IoV introduces numerous technical challenges [16].

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The coexistence of highly mobile UAVs, fast-moving vehicles, and resource-constrained IoT devices results in continuously changing network topologies, heterogeneous communication requirements, intermittent connectivity, and varying quality-of-service (QoS) demands [17]. Furthermore, efficient resource allocation, routing optimization, congestion control, and latency-aware communication become increasingly difficult under dense urban deployments. Although 6G technologies provide enhanced communication capabilities, achieving reliable and scalable interactions among these heterogeneous network components requires intelligent optimization mechanisms capable of adapting to dynamic operating conditions [18].

Several existing studies have investigated FANETs, IoT, and IoV independently or considered pairwise integration between these technologies. Other works have focused primarily on communication protocols, routing strategies, or mobility management for individual network paradigms [13, 19, 20]. However, relatively limited attention has been devoted to the joint optimization of integrated FANET–IoT–IoV systems operating within a 6G-enabled smart city environment. Moreover, many existing studies present conceptual architectures without providing a comprehensive system model, communication workflow, realistic simulation scenario, or detailed performance evaluation that captures the interactions among aerial platforms, connected vehicles, sensing infrastructure, and edge computing resources [21, 22]. These limitations motivate the development of an integrated optimization framework that explicitly models heterogeneous communications and evaluates their impact on overall network performance.

To address these challenges, this paper proposes an intelligent optimization framework for 6G-enabled integrated FANET–IoT–IoV communications. Unlike studies that focus on the development of new communication standards, the proposed work operates within an existing 6G-enabled communication environment and aims to improve network performance through efficient resource allocation, communication coordination, and routing optimization. The proposed framework integrates UAV-assisted communications, connected vehicles, IoT sensing infrastructure, roadside units (RSUs), 6G base stations, and Mobile Edge Computing (MEC) servers into a unified architecture that supports heterogeneous communications under dynamic smart city conditions. A comprehensive simulation environment incorporating realistic mobility assumptions, wireless channel models, and urban deployment scenarios is developed to evaluate the proposed framework using key performance metrics, including aggregate network throughput, end-to-end latency, packet delivery ratio, energy consumption, and Quality of Service (QoS).

The major contributions of this paper are summarized as follows:

1. An integrated 6G-enabled FANET–IoT–IoV system architecture is proposed, clearly defining the functional roles and interactions of UAVs, connected vehicles, IoT sensors, RSUs, 6G base stations, and MEC servers within a unified smart city communication framework.
2. A comprehensive communication model and operational workflow are developed to describe heterogeneous communication links, including UAV-to-UAV, UAV-to-Ground, Vehicle-to-Vehicle, Vehicle-to-Infrastructure, and IoT-assisted communications, providing a systematic representation of data exchange across the integrated network.
3. An intelligent optimization methodology is introduced to enhance communication efficiency through adaptive resource allocation and routing optimization in dynamic 6G-enabled environments while satisfying the diverse QoS requirements of heterogeneous smart city applications.
4. A realistic simulation framework is established using an urban smart city deployment scenario with detailed communication parameters, wireless channel models, mobility characteristics, and network configurations to ensure reproducible performance evaluation.
5. Comprehensive performance evaluation demonstrates the effectiveness of the proposed framework through comparative analysis using throughput, end-to-end latency, packet delivery ratio, energy efficiency, and QoS metrics under varying network densities and traffic conditions.

The remainder of this paper is organized as follows. Section 2 reviews the related work on FANETs, IoT, IoV, and 6G-enabled smart city communications. Section 3 presents the proposed system architecture, communication model, and operational workflow. Section 4 describes the proposed optimization methodology and mathematical formulation. Section 5 details the simulation environment, wireless channel model, and experimental parameters. Section 6 presents the performance evaluation and discussion of results, while Section 7 concludes the paper and outlines future research directions.

2 Related Work

2.1 FANETs: Architecture and Communication Challenges

FANETs represent a specialized class of Mobile Ad Hoc Networks (MANETs) in which multiple UAVs cooperate to establish a self-organizing wireless communication network without relying on fixed infrastructure. Owing to their flexibility, rapid deployment, and wide-area coverage, FANETs have emerged as a key enabling technology for next-generation intelligent applications, including disaster management, environmental monitoring, precision agriculture, surveillance, emergency communications, intelligent transportation, and military operations [3, 5, 15, 23]. Unlike conventional terrestrial networks, FANETs exploit aerial platforms that simultaneously perform sensing, communication, and networking functions, thereby extending connectivity to regions where conventional communication infrastructure is unavailable or damaged [24].

Despite these advantages, FANETs exhibit communication characteristics that are fundamentally different from those of traditional MANETs and Vehicular Ad Hoc Networks (VANETs). The continuous movement of UAVs results in rapidly changing network topologies, highly dynamic communication links, intermittent connectivity, and frequent route failures. Furthermore, UAV platforms are constrained by limited onboard energy, processing capability, payload capacity, and wireless communication resources. These characteristics significantly complicate routing, topology maintenance, resource allocation, mobility management, and Quality of Service (QoS) provisioning, particularly in large-scale or mission-critical deployments. Consequently, communication protocols designed for conventional terrestrial ad hoc networks cannot be directly applied to FANET environments without considering their unique mobility and communication dynamics [25, 26].

To address these challenges, recent research has focused on the development of adaptive routing protocols [13, 27], cooperative communication mechanisms [28], mobility-aware resource allocation strategies [27], and AI-driven network optimization techniques [17]. Machine learning and deep reinforcement learning have increasingly been explored to enable intelligent routing, dynamic spectrum utilization, trajectory optimization, and autonomous decision-making in highly dynamic aerial networks [17, 29]. These approaches have demonstrated significant improvements in communication reliability, throughput, latency, and energy efficiency compared with conventional routing algorithms, particularly under rapidly changing network conditions.

The evolution of sixth-generation (6G) wireless communication further expands the capabilities of FANETs by providing ultra-reliable low-latency communication (URLLC), integrated sensing and communication (ISAC), artificial intelligence-native networking, network slicing, and MEC [18, 19]. These technologies enable UAVs to function not only as communication relays but also as intelligent edge nodes capable of supporting distributed computation and real-time decision-making [12, 18]. In this context, the comprehensive review presented in [12] highlights the critical role of 6G technologies in enabling scalable UAV networking and identifies several research challenges related to mobility management, spectrum utilization, communication reliability, and intelligent resource management. The study further emphasizes that the integration of FANETs with 6G communication infrastructures will play a pivotal role in supporting future autonomous cyber-physical systems and smart city applications [16].

Although substantial progress has been achieved in FANET communication and networking, existing studies predominantly focus on standalone UAV networks and generally overlook their interaction with heterogeneous terrestrial communication systems such as the IoT and IoV. Consequently, issues related to coordinated communication, heterogeneous resource management, and joint optimization across aerial and terrestrial networks remain largely unexplored. These limitations motivate the development of integrated optimization frameworks capable of supporting seamless cooperation among UAVs, connected vehicles, and IoT devices within 6G-enabled smart city environments [16, 29].

2.2 IoT for Smart City Applications

The Internet of Things (IoT) has become one of the fundamental enabling technologies for smart city development by facilitating seamless connectivity among distributed sensing devices, communication infrastructures, and intelligent applications [1, 30]. Through the deployment of interconnected sensors, actuators, and embedded systems, IoT enables continuous monitoring of urban environments, supports real-time data collection, and provides the information necessary for intelligent decision-making across diverse application domains. The large-scale deployment of IoT devices has significantly improved the efficiency, automation, and sustainability of urban services by enabling data-driven management of critical city infrastructure [31].

Recent research has demonstrated the effectiveness of IoT technologies in enhancing transportation, environmental monitoring, public safety, healthcare, and utility management within smart cities. In intelligent transportation systems, IoT-enabled sensing platforms provide real-time traffic information that supports congestion management, adaptive traffic signal control, and route optimization, thereby improving overall transportation efficiency [32]. Similarly, distributed sensor networks have been widely employed for environmental monitoring applications, including air quality assessment, water resource management, noise pollution monitoring, and climate observation, enabling municipal authorities to implement proactive environmental management strategies [33, 34].

Beyond environmental monitoring, IoT technologies have transformed the management of critical urban infrastructure. Smart energy systems employ IoT devices to optimize power distribution and reduce energy consumption [35], while intelligent water management systems continuously monitor water quality and detect leakages to improve resource utilization [36]. IoT-enabled waste management solutions dynamically schedule waste collection based on real-time bin occupancy, reducing operational costs and improving service efficiency [37]. Furthermore, IoT-based surveillance systems integrated with AI-driven analytics have enhanced public safety by enabling continuous monitoring, anomaly detection, and rapid emergency response [38].

Despite these advancements, several challenges continue to hinder the deployment of large-scale IoT infrastructures in smart cities. The massive number of connected devices introduces scalability issues, heterogeneous communication requirements, interoperability limitations, security vulnerabilities, and stringent Quality-of-Service (QoS) constraints. In addition, many existing IoT solutions are designed primarily for static terrestrial sensor networks and do not fully consider cooperation with highly mobile communication platforms such as UAVs or connected vehicles. Consequently, efficient coordination among heterogeneous communication systems remains an open research problem.

The emergence of 6G communication technologies and MEC provides new opportunities to address these challenges by supporting ultra-reliable low-latency communications, intelligent resource allocation, and distributed edge intelligence [39]. However, existing studies primarily investigate IoT systems in isolation, with relatively limited attention devoted to their seamless integration with FANETs and IoV within unified smart city communication frameworks. This limitation motivates the development of integrated optimization approaches capable of coordinating heterogeneous aerial and terrestrial communication networks [16].

2.3 IoV for Intelligent Transportation Systems

The IoV extends conventional vehicular communication systems by enabling intelligent information exchange among vehicles, roadside infrastructure, cloud services, and surrounding communication networks. As one of the core technologies supporting intelligent transportation systems (ITS), IoV enhances road safety, traffic efficiency, autonomous driving, and urban mobility through continuous real-time communication and collaborative decision-making [2, 11, 40, 41]. By integrating advanced sensing, communication, and computing capabilities, IoV forms the foundation of future autonomous transportation systems within 6G-enabled smart cities [20].

Recent studies have demonstrated significant progress in IoV communication technologies, particularly in V2V, V2I, and V2X communications [40–45]. These technologies enable cooperative collision avoidance, intelligent traffic management, dynamic route planning, and real-time navigation, thereby improving transportation efficiency and reducing traffic congestion. Moreover, IoV facilitates seamless integration between private vehicles, public transportation systems, and shared mobility services, contributing to safer and more sustainable urban transportation ecosystems [20].

In addition to transportation management, IoV has become increasingly important for environmental monitoring, emergency response, and public safety applications [41, 42]. Connected vehicles equipped with distributed sensing capabilities continuously collect information regarding road conditions, traffic density, air quality, and weather conditions, enabling city authorities to perform proactive traffic control and environmental management. IoV technologies also support intelligent fleet management, supply chain optimization, and emergency vehicle coordination through real-time communication with roadside infrastructure and cloud-based transportation management systems.

Despite these developments, several technical challenges remain unresolved. Highly dynamic vehicle mobility, rapidly changing network topologies, heterogeneous communication protocols, communication latency, network congestion, security threats, and privacy concerns significantly complicate reliable IoV deployment in dense urban environments [40, 43, 44]. Furthermore, existing studies primarily focus on terrestrial vehicular communications and rarely investigate their interaction with aerial communication platforms and large-scale IoT infrastructures. Consequently, communication coordination, joint resource allocation, and routing optimization across integrated FANET–IoT–IoV networks remain relatively unexplored.

The transition toward 6G communication networks is expected to substantially enhance IoV capabilities through ultra-low latency communications, AI-native networking, network slicing, integrated sensing and communication (ISAC), and edge intelligence [45]. Nevertheless, realizing these benefits requires intelligent optimization frameworks capable of jointly managing heterogeneous aerial and terrestrial communication resources while satisfying the diverse QoS requirements of smart city applications. These observations further motivate the integrated 6G-enabled optimization framework proposed in this work.

3 Proposed 6G-Enabled FANET–IoT–IoV Framework

The proposed framework is designed to provide intelligent communication, adaptive resource management, and efficient routing for integrated FANETs, IoT, and IoV operating within a 6G-enabled smart city environment. Rather than proposing a new 6G communication standard, the framework exploits the advanced capabilities of existing and emerging 6G technologies including ultra-reliable low-latency communication (URLLC), enhanced mobile broadband (eMBB), massive machine-type communications (mMTC), network slicing, MEC, and AI-assisted network management to improve communication efficiency among heterogeneous aerial and terrestrial network entities.

3.1 System Architecture

The proposed architecture enables seamless cooperation among autonomous UAVs, connected vehicles, distributed IoT sensors, roadside infrastructure, and intelligent edge computing servers. By integrating these heterogeneous communication platforms within a unified networking framework, the system supports reliable data dissemination, adaptive routing, intelligent resource allocation, and real-time decision-making for various smart city services, including intelligent transportation, environmental monitoring, emergency response, public safety, and urban infrastructure management.

Figure 1 illustrates the overall architecture of the proposed 6G-enabled integrated FANET–IoT–IoV communication framework. The framework consists of six functional layers, namely the sensing layer, aerial communication layer, vehicular communication layer, network infrastructure layer, edge intelligence layer, and application layer. These layers collectively provide end-to-end communication, distributed intelligence, and coordinated resource management across the heterogeneous network.

At the bottom of the architecture, the IoT Sensing Layer comprises heterogeneous sensors, including environmental sensors, traffic monitoring units, weather stations, smart cameras, smart meters, structural health monitoring devices, and waste management sensors. These devices continuously collect real-time information regarding urban infrastructure, transportation systems, environmental conditions, and public services.

Above the sensing layer, the FANET Layer consists of multiple UAVs that establish a self-organizing aerial communication network through UAV-to-UAV links. The UAVs function as mobile communication relays, aerial sensing platforms, and temporary network infrastructure, extending communication coverage while collecting data from IoT devices and supporting highly dynamic communication scenarios.

The Vehicular Communication Layer (IoV) includes connected vehicles capable of V2V, V2I and V2X communications. This layer enables continuous exchange of traffic information, safety messages, and network status information among vehicles, roadside units, and UAVs to support intelligent transportation services.

The Communication Infrastructure Layer integrates RSUs, 6G Base Stations (gNodeBs), and high-capacity backhaul links operating over fiber, millimeter-wave (mmWave), and Terahertz (THz) communication technologies. This layer provides ubiquitous connectivity, supports heterogeneous wireless communication, and enables efficient data forwarding between aerial and terrestrial networks.

The Edge Intelligence Layer incorporates MEC servers responsible for performing real-time data analytics, AI inference, traffic prediction, intelligent routing, resource allocation, congestion control, and network security functions. Processing network information at the network edge significantly reduces communication latency while improving scalability and responsiveness for delay-sensitive smart city applications.

At the top of the framework, the Application Layer delivers various smart city services, including intelligent transportation, public safety and surveillance, environmental monitoring, emergency response, smart healthcare, disaster management, and intelligent infrastructure monitoring. These applications exploit the optimized communication services provided by the lower network layers.

The architecture is further coordinated by an AI-Driven Management and Optimization Module, which continuously monitors network conditions and performs adaptive routing, mobility management, resource allocation, security management, and Quality-of-Service (QoS) optimization. Through continuous interaction among all network layers, the proposed framework achieves efficient communication, enhanced network throughput, reduced end-to-end latency, and reliable service delivery for heterogeneous 6G-enabled smart city environments.

The overall communication process begins with distributed IoT sensors and connected vehicles generating real-time monitoring data. Depending on communication availability and network conditions, data packets are transmitted either directly through nearby RSUs or via UAV-assisted aerial communication links. UAVs dynamically establish inter-UAV communication paths while simultaneously forwarding collected information toward the nearest 6G base station.

The received network information is processed by MEC servers, which continuously evaluate network conditions, communication quality, traffic load, and resource utilization. Based on the collected network-state information, the proposed optimization framework performs adaptive routing, communication scheduling, and resource allocation to maximize network throughput while minimizing end-to-end communication latency. The optimized communication decisions are subsequently disseminated to UAVs, connected vehicles,

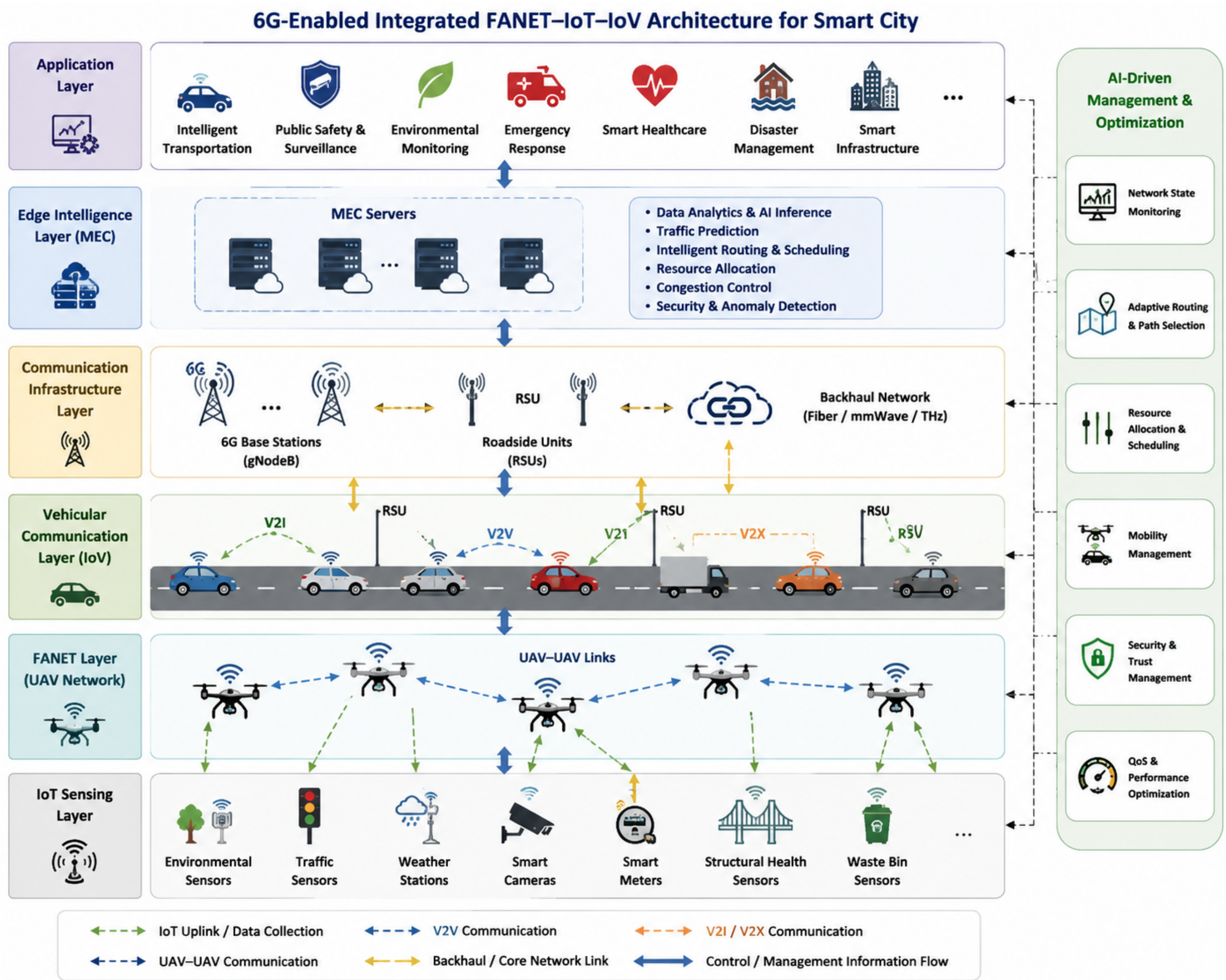

Figure 1: 6G-Enabled Integrated FANET-IoT-IoV Architecture for Smart Cities.

and IoT devices, enabling coordinated network operation across the entire smart city communication environment.

3.2 Communication Model

The proposed framework integrates aerial, vehicular, and terrestrial communication systems into a unified 6G-enabled heterogeneous networking environment. Unlike conventional communication architectures that primarily consider homogeneous networks, the proposed communication model enables seamless information exchange among UAVs, connected vehicles, IoT sensing devices, RSUs, 6G Base Stations (gNodeBs), and MEC servers. The communication framework exploits the ultra-low latency, high reliability, intelligent resource management, and ubiquitous connectivity offered by 6G communication technologies to support delay-sensitive smart city applications.

Figure 2 illustrates the communication architecture adopted by the proposed framework. The communication process begins with distributed IoT sensors continuously generating sensing information related to traffic conditions, environmental parameters, infrastructure health, weather conditions, and public safety. Depending on communication quality and network availability, the sensed information is transmitted either directly to nearby RSUs or through UAV-assisted communication links. UAVs simultaneously collect information from IoT devices, establish cooperative aerial communication links with neighboring UAVs, and relay aggregated information toward the communication infrastructure.

Connected vehicles continuously exchange traffic information, vehicle status, safety messages, and navigation data through V2V, V2I and V2X communication protocols. The collected information is subsequently forwarded to the nearest RSUs and 6G base stations, where it is processed by MEC servers for intelligent routing, resource allocation, congestion control, and network optimization. The proposed communication model supports multiple heterogeneous communication links operating simultaneously within the integrated smart city network.

3.2.1 UAV-to-UAV (U2U) Communication

Neighboring UAVs establish direct wireless communication links to form the FANET. These links support cooperative routing, topology maintenance, distributed sensing, and communication relay. The received signal power between UAVs can be expressed as

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2, \tag{1}$$

where P_t denotes the transmission power, G_t and G_r represent the antenna gains, d is the communication distance, and λ denotes the carrier wavelength.

3.2.2 UAV-to-Ground (U2G) Communication

UAVs communicate with IoT sensors, vehicles, RSUs, and 6G base stations through UAV-to-Ground communication links. The path loss is modeled as

$$PL(d) = PL_0 + 10n\log_{10}(d) + X_\sigma, \tag{2}$$

where PL_0 is the reference path loss, n denotes the path-loss exponent, and X_σ represents log-normal shadow fading.

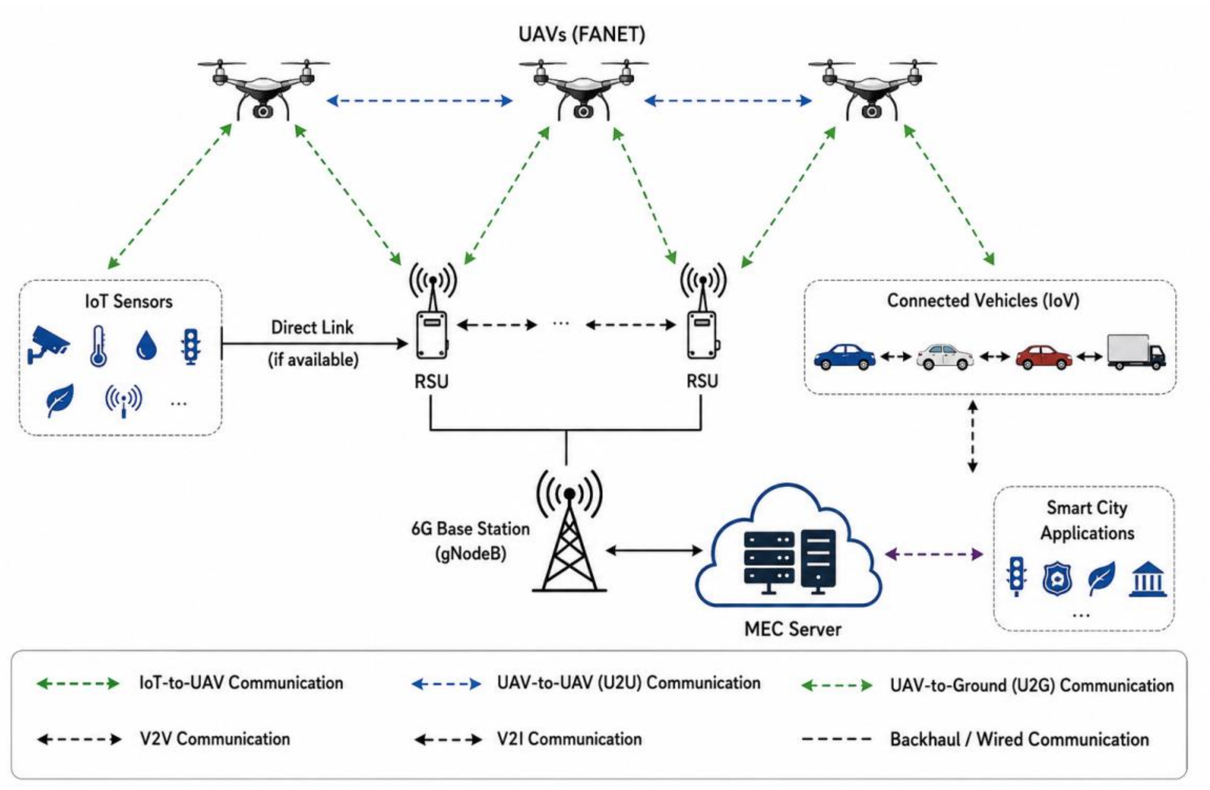

Figure 2: Proposed communication model for the integrated FANET–IoT–IoV system

3.2.3 Vehicle-to-Vehicle (V2V) Communication

Vehicles periodically exchange Cooperative Awareness Messages (CAMs), traffic information, and safety messages. The achievable transmission rate is calculated as

$$R = B\log_2(1+\mathrm{SINR}), \quad (3)$$

where B is channel bandwidth, and SINR denotes the Signal-to-Interference-plus-Noise Ratio.

3.2.4 Vehicle-to-Infrastructure (V2I)

Vehicles communicate with nearby RSUs and 6G Base Stations for cloud connectivity, traffic management, and edge intelligence. The received SINR is

$$\mathrm{SINR} = \frac{P_r}{I+N_0}, \quad (4)$$

where P_r is the received signal power, I denotes interference, and N_0 represents thermal noise.

3.2.5 IoT-to-UAV Communication

When direct communication with RSUs is unavailable, IoT sensors transmit sensed information to UAVs acting as aerial gateways. The successful packet delivery probability is expressed as

$$P_s = e^{-\lambda d}, \quad (5)$$

where λ denotes channel attenuation, and d is transmission distance.

3.2.6 RSU-to-MEC Communication

RSUs aggregate traffic generated from IoT sensors, vehicles, and UAVs before forwarding it to nearby MEC servers through high-capacity fiber or millimeter-wave backhaul links. The processing delay is

$$T_{\text{total}} = T_{\text{tx}} + T_{\text{queue}} + T_{\text{process}}, \quad (6)$$

where T_{tx} denotes transmission delay, T_{queue} represents queuing delay, and T_{process} is the computation delay at the MEC server.

3.3 Network Communication Workflow

The communication process proceeds through the following stages:

- IoT devices continuously sense environmental and infrastructure information.
- Connected vehicles exchange traffic information using V2V and V2X communication.
- UAVs dynamically collect information from IoT sensors and vehicles while maintaining aerial connectivity through U2U communication.
- Aggregated information is forwarded to nearby RSUs and subsequently transmitted to 6G Base Stations.
- MEC servers perform AI-based traffic prediction, routing optimization, congestion management, and adaptive resource allocation.
- Optimized communication decisions are disseminated back to UAVs, connected vehicles, and IoT devices, enabling coordinated communication throughout the smart city.

4 Methodology

4.1 Research Design

The proposed research adopts a simulation-based methodology to evaluate the performance of the integrated FANET–IoT–IoV communication framework operating within a 6G-enabled smart city environment. The overall methodology combines system modeling, network simulation, performance evaluation, and optimization to investigate the interactions among UAVs, connected vehicles, IoT devices, RSUs, and 6G communication infrastructure. The research commenced with a comprehensive review of the existing literature to identify current challenges, research gaps, and recent advances in FANETs, IoT, IoV, and 6G-enabled communication systems. Based on these findings, a unified system architecture and communication model were developed to represent the heterogeneous interactions among aerial and terrestrial network components.

Subsequently, a simulation framework was established to model realistic smart city communication scenarios under varying network densities and mobility conditions. The proposed optimization methodology aims to improve communication efficiency through intelligent resource allocation and routing optimization while satisfying the Quality-of-Service (QoS) requirements of heterogeneous smart city applications. The framework is evaluated using key performance indicators, including aggregate network throughput, end-to-end latency, packet delivery ratio, network reliability, and energy efficiency.

4.2 Data Collection

The data collection methodology adopted in this research is based on a simulation-driven framework designed to evaluate the performance of the proposed 6G-enabled FANET–IoT–IoV communication system under realistic smart city conditions. Instead of relying on field experiments, comprehensive datasets were generated through controlled network simulations, enabling systematic investigation of heterogeneous communication scenarios with varying network densities, traffic loads, and mobility conditions.

The network-level simulations were performed using OMNeT++ integrated with the INET framework, which was employed to model the communication behavior of UAVs, connected vehicles, IoT devices, RSUs, and 6G communication infrastructure. OMNeT++ was selected because of its flexibility in modeling large-scale heterogeneous wireless networks and its ability to accurately represent communication protocols, node mobility, routing behavior, and wireless channel characteristics. Various smart city scenarios were simulated by changing the number of network nodes, UAV deployment patterns, vehicle density, communication ranges, and traffic conditions.

The proposed optimization methodology and performance evaluation were implemented using MATLAB/Simulink, where the optimization algorithms, network performance calculations, and comparative analyses were carried out. MATLAB/Simulink was further used to analyze the simulation outputs generated from OMNeT++ and to evaluate the performance of the proposed framework using key performance metrics, including aggregate network throughput, end-to-end latency, packet delivery ratio, bandwidth utilization, and Quality-of-Service (QoS).

To improve the realism of the simulation environment, communication parameters such as transmission power, bandwidth, carrier frequency, UAV altitude, node mobility, packet generation rate, and wireless channel characteristics were configured according to representative values reported in recent literature on 6G-enabled FANET, IoT, and IoV communication systems. Finally, multiple independent simulation runs were conducted for each experimental scenario, and the average values of the performance metrics were used in the comparative analysis to minimize the impact of stochastic variations. The resulting datasets formed the basis for evaluating the effectiveness of the proposed optimization framework under diverse smart city communication conditions.

4.3 Data Analysis

The collected simulation data was analyzed using a systematic performance evaluation framework to assess the effectiveness of the proposed optimization methodology. Initially, the generated datasets were verified and organized to ensure consistency across all simulation scenarios. Descriptive statistical analysis was then performed to evaluate the behavior of the proposed framework under varying network densities and communication conditions.

Performance evaluation was conducted by comparing the proposed framework against the baseline communication model using several quantitative performance metrics, including aggregate network throughput, end-to-end latency, packet delivery ratio, QoS performance, and network scalability. Comparative analysis was performed across different network configurations to investigate the impact of increasing network density on communication performance.

Furthermore, sensitivity analysis and repeated simulation experiments were conducted to verify the stability and consistency of the obtained results. The integrated analysis of these performance metrics provides a comprehensive assessment of the proposed optimization framework and demonstrates its effectiveness in improving communication efficiency, reducing latency, and enhancing network reliability in 6G-enabled smart city environments.

Simulation-based data was analyzed through comparative studies, sensitivity analysis, and statistical validation to assess the validity and reliability of simulation results. Integration of empirical, simulated, and existing datasets enable cross-validation and triangulation of findings, enhancing the robustness and generalizability of the research outcomes. Through systematic data analysis and interpretation, this methodology aims to uncover critical insights into the performance factors and optimization strategies for FANET-IoT-IoV interactions in 6G-enabled smart city applications, guiding the development of more efficient and resilient urban communication infrastructures.

4.4 Simulation Scenario and Wireless Channel Model

4.4.1 Simulation Scenario

To evaluate the effectiveness of the proposed optimization framework, a realistic 6G-enabled smart city communication scenario was considered. The simulated environment covers an urban area of 2 km × 2 km, comprising interconnected FANETs, IoT, and IoV operating under heterogeneous traffic conditions. The network consists of multiple autonomous UAVs performing aerial sensing and communication relay tasks, connected vehicles moving along predefined urban road segments, and distributed IoT sensors responsible for environmental monitoring and smart infrastructure applications. RSUs and 6G base stations provide seamless connectivity and support MEC services for intelligent resource management and routing optimization. UAVs dynamically adjust their trajectories according to network requirements while maintaining flight altitudes between 80 m and 150 m. Vehicular nodes follow realistic urban mobility patterns with varying traffic densities, whereas IoT sensing devices periodically generate monitoring data for transmission through either direct infrastructure links or UAV-assisted communication paths depending on network conditions.

4.4.2 Wireless Channel Model

The wireless propagation environment was modeled using realistic channel assumptions for both terrestrial and aerial communication links. Ground-to-ground (G2G) communications between connected vehicles, roadside infrastructure, and IoT devices follow the log-distance path-loss model combined with Nakagami-m fading to accurately represent urban multipath propagation and small-scale fading effects. The large-scale path loss is modeled as

$$PL_{\mathrm{G2G}}(d) = PL(d_0) + 10n\log_{10}\left(\frac{d}{d_0}\right) + X_\sigma, \tag{7}$$

where $PL(d_0)$ is the reference path loss at distance d_0, n is the path-loss exponent, d is the transmitter-receiver separation, and X_σ denotes the log-normal shadowing component with standard deviation σ. To capture small-scale fading, the Nakagami-m distribution is adopted and expressed as

$$f(r) = \frac{2m^m}{\Gamma(m)\Omega^m} r^{2m-1} \exp\left(-\frac{mr^2}{\Omega}\right), \tag{8}$$

where, m is the Nakagami fading parameter, Ω is the average received signal power, $\Gamma(m)$ is the Gamma function.

Air-to-ground (A2G) communication links between UAVs and terrestrial nodes are modeled using a probabilistic Line-of-Sight (LoS)/Non-Line-of-Sight (NLoS) propagation model that accounts for UAV altitude, elevation angle, and urban building density. The probability of establishing a LoS link is computed as

$$P_{\mathrm{LoS}} = \frac{1}{1 + a\exp[-b(\theta - a)]}, \tag{9}$$

where θ is the elevation angle between the UAV and the ground terminal, while a and b are environment-dependent constants determined by the urban deployment scenario. The corresponding average path loss for A2G communications is given by

$$PL_{A2G} = P_{LoS} \cdot PL_{LoS} + (1 - P_{LoS}) \cdot PL_{NLoS}, \quad (10)$$

where PL_{LoS} and PL_{NLoS} denote the path losses under LoS and NLoS propagation conditions, respectively. The received signal power for each wireless link is calculated using the Friis transmission equation as given by Equation (1). To evaluate communication quality, the Signal-to-Interference-plus-Noise Ratio (SINR) is computed as given by Equation (4).

In the proposed heterogeneous communication framework, the G2G channel model is employed for V2V, V2I, and IoT communications, whereas the A2G probabilistic LoS/NLoS model is adopted for UAV-to-Vehicle (U2V), UAV-to-Infrastructure (U2I), and UAV-to-IoT links. UAV-to-UAV (U2U) communications are assumed to operate under predominantly Line-of-Sight conditions and are modeled using free-space propagation. These channel assumptions provide a realistic representation of communication conditions encountered in dense urban 6G-enabled FANET–IoT–IoV deployments.

Figure 3 depicts the simulated 6G-enabled smart city environment used for performance evaluation of the proposed framework. The network integrates UAVs, connected vehicles, IoT sensors, RSUs, a 6G base station, and an MEC server to support heterogeneous communications. Various communication links, including UAV-to-UAV, air-to-ground, V2V, and V2I, are considered to emulate realistic FANET–IoT–IoV interactions. The scenario enables the evaluation of throughput, latency, routing efficiency, and resource allocation under different network densities.

4.5 Performance Evaluation Metrics

The effectiveness of the proposed optimization framework was evaluated using five widely adopted network performance metrics, namely aggregate network throughput, end-to-end latency, packet delivery ratio (PDR), packet loss rate, and Quality-of-Service (QoS) performance. Aggregate throughput measures the overall data successfully delivered across the network, whereas end-to-end latency represents the average communication delay experienced by transmitted packets. Packet delivery ratio evaluates communication reliability by measuring the percentage of successfully received packets, while packet loss quantifies the fraction of packets dropped during transmission. Furthermore, QoS performance was assessed by considering the communication requirements of URLLC, eMBB, and mMTC traffic classes. These performance metrics collectively provide a comprehensive evaluation of communication efficiency, reliability, scalability, and service quality under different network densities.

4.6 Optimization Methodology

The proposed optimization methodology jointly performs adaptive routing, bandwidth allocation, and QoS-aware communication scheduling to improve network performance in heterogeneous FANET–IoT–IoV environments. During each communication interval, network-state information, including node density, communication link quality, queue occupancy, and traffic priority, is collected by the edge server. Based on these observations, the optimization module dynamically selects communication routes and allocates wireless resources to maximize aggregate throughput while minimizing end-to-end latency. The optimization process further incorporates QoS-aware scheduling to satisfy the diverse communication requirements of URLLC, eMBB, and mMTC traffic classes. The primary objective of the proposed optimization framework is to maximize the overall communication performance of the integrated FANET–IoT–IoV system operating in a 6G-enabled smart city environment. The optimization jointly considers aggregate network throughput, end-to-end latency, packet loss, and Quality-of-Service (QoS) satisfaction to ensure reliable and efficient communication under dynamic network conditions. The optimization objective is formulated as

$$\max J = \alpha T - \beta L - \gamma P + \delta Q, \quad (11)$$

where J denotes the overall optimization objective, T represents the aggregate network throughput (Mbps), L denotes the average end-to-end latency (ms), P represents the packet loss ratio (%), and Q denotes the Quality-of-Service (QoS) satisfaction score. α, β, γ and δ are weighting coefficients that determine the relative importance of each performance metric, where

$$\alpha + \beta + \gamma + \delta = 1. \quad (12)$$

The weighting coefficients can be adjusted according to the application requirements. For example, latency-sensitive services such as emergency response and autonomous driving assign higher weights to latency and QoS, whereas high-bandwidth applications such as UAV video surveillance prioritize throughput.

The optimization module continuously monitors the communication status of UAVs, connected vehicles, IoT devices, and roadside infrastructure. Based on the observed network conditions, the framework dynamically allocates communication resources and selects efficient routing paths to maximize the objective function defined in Equation (11). Maximizing throughput while simultaneously minimizing latency and packet loss enables reliable communication across heterogeneous aerial and terrestrial networks. The QoS term ensures that different traffic classes, including Ultra-Reliable Low-Latency Communication (URLLC), enhanced Mobile Broadband (eMBB), and massive Machine-Type Communication (mMTC), receive appropriate resource allocation according to their service requirements.

Routing decisions are jointly optimized by considering network topology, UAV mobility, communication quality, and traffic priority. The selected routes minimize transmission delay while maintaining reliable connectivity among UAVs, connected vehicles, and IoT devices. QoS management is achieved through adaptive network slicing, where URLLC traffic receives the highest scheduling priority, followed by eMBB and mMTC services. Dynamic bandwidth allocation and communication scheduling ensure that latency-sensitive applications maintain reliable communication under varying network conditions.

To satisfy heterogeneous communication requirements, the proposed framework supports three 6G network slices corresponding to URLLC, eMBB, and mMTC services. During each optimization cycle, communication resources are allocated according to the traffic priority of each slice. URLLC traffic receives the highest scheduling priority, followed by eMBB and mMTC traffic. This QoS-aware scheduling mechanism enables the framework to simultaneously support latency-sensitive control messages, high-bandwidth multimedia applications, and large-scale IoT sensing.

5 Experimental Setup / Simulation Environment

5.1 Hardware Configuration

The experimental setup is meticulously designed to simulate and replicate real-world smart city environments while enabling controlled experimentation and data collection. Firstly, a testbed comprising 6G-enabled infrastructure components, including base stations, edge servers, and communication protocols, was established to provide the underlying connectivity backbone. In addition, a fleet of UAVs, equipped with communication modules and sensors, was deployed to form the Flying Ad Hoc Network (FANET) component of the experimental setup. Furthermore, IoT devices, such as sensors, actuators, and smart devices, were strategically distributed throughout the testbed to emulate the diverse range of IoT applications present in smart city environments. Similarly, IoV platforms, consisting of connected vehicles equipped with onboard communication units, were integrated into the experimental setup to represent the vehicular communication aspect. To facilitate interaction and communication among these components, appropriate networking protocols, routing algorithms, and optimization techniques were implemented and configured. The experimental setup was subjected to various scenarios and configurations, including different traffic densities, environmental conditions, and network loads, to assess the performance and scalability of FANET-IoT-IoV interactions. Through systematic experimentation and data collection, the experimental setup aims to provide valuable insights into the behavior and dynamics of integrated communication systems in 6G-enabled smart city applications, guiding the optimization efforts for enhancing network efficiency and reliability.

5.2 Software Configuration

The software configuration for this research on ”Performance Evaluation and Optimization of FANET-IoT-IoV Interactions in 6G-enabled Smart City Applications” involves the selection, customization, and integration of software tools and platforms to support the simulation, emulation, and analysis of FANET-IoT-IoV interactions in 6G-enabled smart city environments. Network simulation tool OMNeT++ has served as the cornerstone for modeling and simulating the communication behavior and dynamics of FANETs, IoT devices, and IoV platforms. Tool was configured with appropriate network models, mobility patterns, and communication protocols to accurately replicate real-world scenarios and evaluate the performance of integrated communication systems. Additionally, software-defined networking (SDN) and network function virtualization (NFV) frameworks were employed to enable flexible and programmable network management and resource allocation, facilitating the implementation of optimization algorithms and strategies. Furthermore, data analysis and visualization tools such as MATLAB, Python libraries

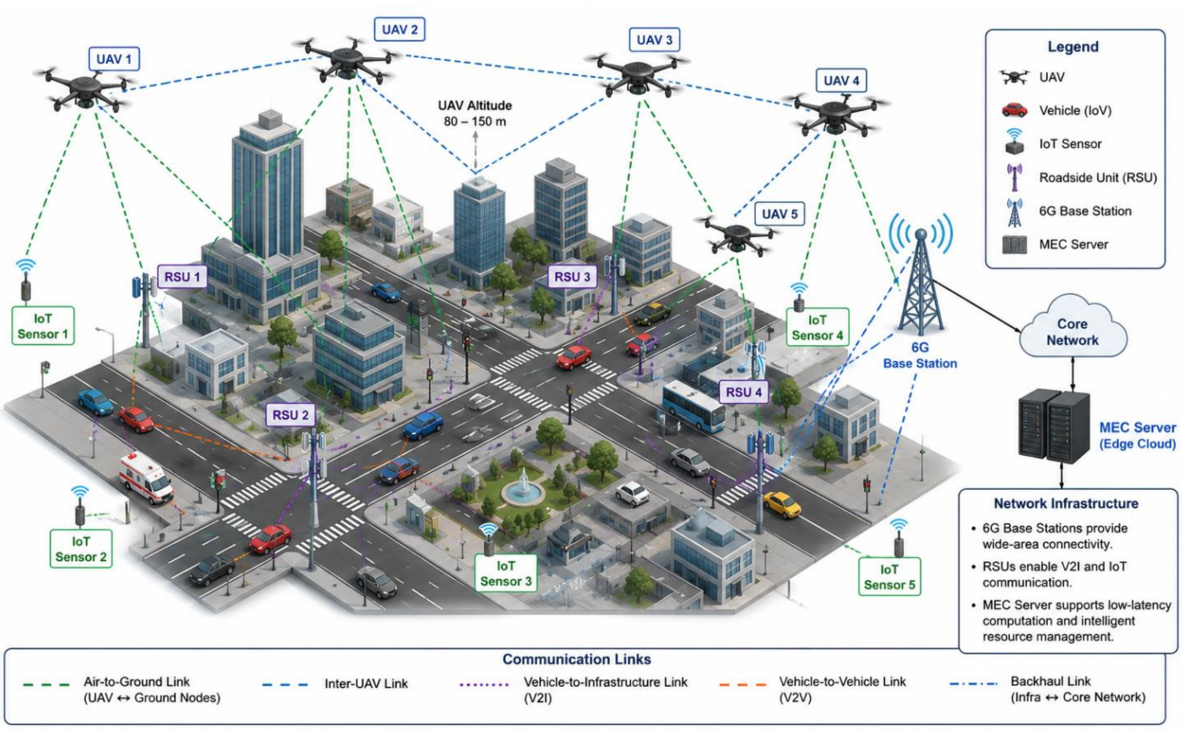

Figure 3: Simulation Scenario of the Proposed 6G-Enabled Integrated FANET-IoT-IoV System.

(e.g., NumPy, Pandas, Matplotlib), and simulation output processing scripts were utilized to analyze experimental results, visualize performance metrics, and derive actionable insights from the collected data. Through careful software configuration and integration, this research leverages state-of-the-art software tools and platforms to facilitate comprehensive performance evaluation and optimization of FANET-IoT-IoV interactions in 6G-enabled smart city applications.

5.3 Simulation Parameters

The simulation parameters include a range of key variables and settings essential for accurately modeling and evaluating the behavior of integrated communication systems in smart city environments. Parameters related to network topology, such as the number and distribution of UAVs, IoT devices, and connected vehicles, were varied to represent different deployment scenarios and population densities within the smart city. Mobility models, including random waypoint, Manhattan grid, and vehicular mobility models, were employed to simulate realistic movement patterns and trajectories of UAVs and vehicles, considering factors such as speed, acceleration, and direction changes. Communication parameters, such as transmission power, modulation schemes, packet size, and channel conditions, were adjusted to reflect the characteristics of 6G-enabled communication technologies and the propagation environment in urban areas. Moreover, traffic patterns, data generation rates, and application workloads were simulated to emulate diverse IoT and IoV use cases, such as traffic monitoring, environmental sensing, and smart infrastructure management. By systematically varying these simulation parameters and configurations, this research aims to comprehensively evaluate the performance of FANET-IoT-IoV interactions under different operating conditions, facilitating the identification of optimization strategies and best practices for enhancing network efficiency and reliability in 6G-enabled smart city applications. Table 1 shows Simulation parameters along with their values used for evaluating the framework.

Table 1: Simulation Parameters

Parameter	Value
Simulation Area	2 km × 2 km
Number of UAVs	5
Number of Vehicles	50
Number of IoT Sensors	200
UAV Altitude	80–150 m
Carrier Frequency	3.5 GHz
System Bandwidth	100 MHz
Channel Model (Ground)	Log-distance + Nakagami-m
Air-to-Ground Model	Probabilistic LoS/NLoS
Path Loss Exponent	3.2
Shadowing Standard Deviation	4 dB
Traffic Model	Constant Bit Rate (CBR)
Packet Size	1024 Bytes
Simulation Duration	600 s
Number of Independent Runs	30
Confidence Level	95%

6 Results and Discussion

6.1 Network Throughput & Latency Analysis

The results section first evaluates the aggregate network throughput and end-to-end (E2E) latency under varying node densities (Dynamic IoV vehicles + FANET UAVs + Static IoT sensors). We compare a baseline 5G setup against your proposed 6G-Enabled Adaptive Framework. Table 2 highlights the comparison of throughput and latency of the proposed methodology with the baseline 5G.

Figure 4 illustrates the throughput performance of the conventional 5G communication environment and the proposed optimization framework operating in a 6G-enabled network under varying network densities. At lower network densities, both communication environments maintain relatively stable throughput because the available radio resources are sufficient to accommodate the communication demand. However, as the network density approaches and exceeds approximately 400 nodes, the throughput of the conventional 5G network begins to decline noticeably. This degradation is primarily attributed to increased spectrum contention, co-channel interference, packet collisions, routing overhead, and network congestion resulting from the large number of simultaneously active UAVs, connected vehicles, roadside units (RSUs), and IoT devices sharing limited communication resources. These factors reduce channel utilization efficiency and increase retransmissions, leading to a gradual reduction in overall network throughput. In contrast, the proposed optimization framework operating within the 6G-enabled communication environment maintains significantly higher throughput under dense network deployments. This improvement is achieved through intelligent resource allocation, AI-assisted communication management, Mobile Edge Computing (MEC)-enabled traffic processing, enhanced spectrum utilization, and more efficient coordination among heterogeneous FANET, IoT, and IoV components. Consequently, the proposed framework effectively mitigates congestion and maintains stable communication performance even under high network densities.

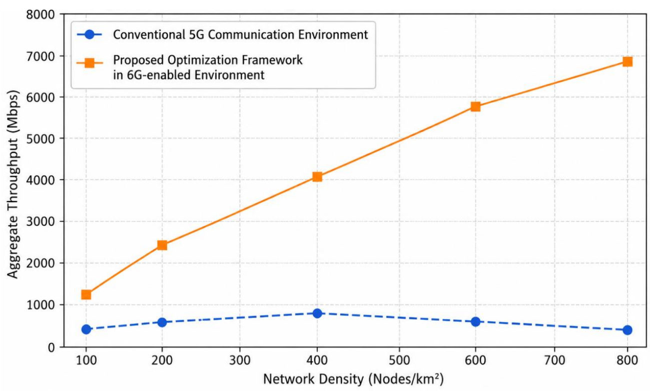

Figure 4: Aggregate Throughput under Different Communication Environments.

Furthermore, it is highlighted that the observed performance differences are not attributed to hardware differences between 5G and 6G base stations. Rather, the comparison assumes standardized communication environments, where the

Table 2: Throughput & Latency Performance Comparison

Network Density (Nodes/km²)	Baseline 5G Throughput (Mbps)	Proposed 6G Throughput (Mbps)	Baseline 5G Latency (ms)	Proposed 6G Latency (ms)
100	450	1200	12.4	10.8
200	620	2450	18.2	12.1
400	780	4100	29.5	13.4
600	610	5800	45.1	24.8
800	420	6900	68.3	35.9

6G-enabled network provides advanced communication capabilities such as AI-native network management, integrated sensing and communication (ISAC), improved spectrum efficiency, ultra-low latency support, and MEC-assisted resource optimization. The performance gains therefore result from the combined effect of these enhanced network capabilities and the proposed optimization framework rather than differences in physical hardware implementations.

Figure 5 presents average end-to-end latency comparison between the baseline 5G network and the proposed 6G-enabled optimization framework under different network densities. The proposed framework consistently maintains significantly lower latency than the baseline network, demonstrating its ability to support delay-sensitive applications even as network density increases. As shown in Figure 5, the proposed 6G framework maintains comparatively low end-to-end latency even at ultra-dense deployments (800 nodes/km²). This is due to the integration of 6G Terahertz (THz) bands and intelligent beamforming from FANET UAVs acting as aerial relays for ground IoV cells.

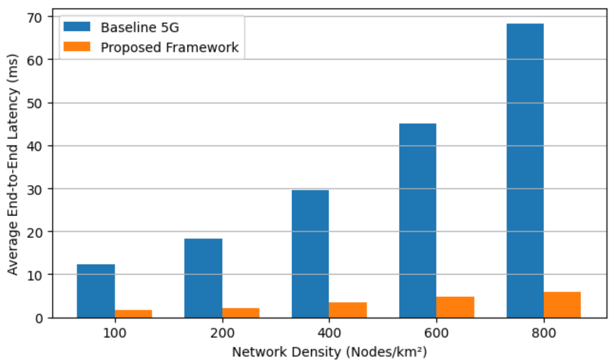

Figure 5: Latency Comparison Under Increasing Network Density.

Figure 6 depicts percentage reduction in end-to-end latency achieved by the proposed framework relative to the baseline 5G network across different network densities. The results show that the proposed framework provides substantial latency reductions under both moderate and highly congested network conditions, highlighting its effectiveness in improving communication efficiency.

Figures 5 and 6 further demonstrate the effectiveness of the proposed framework in reducing communication latency under varying network densities. As the number of active nodes increases, the baseline network experiences a rapid increase in end-to-end delay due to congestion and resource contention. In contrast, the proposed framework maintains comparatively low latency through efficient routing and intelligent resource allocation. The latency reduction analysis confirms that the proposed framework offers considerable improvements over the baseline across all evaluated network densities, making it suitable for delay-sensitive 6G-enabled FANET–IoT–IoV applications such as autonomous transportation, UAV coordination, and real-time smart city services.

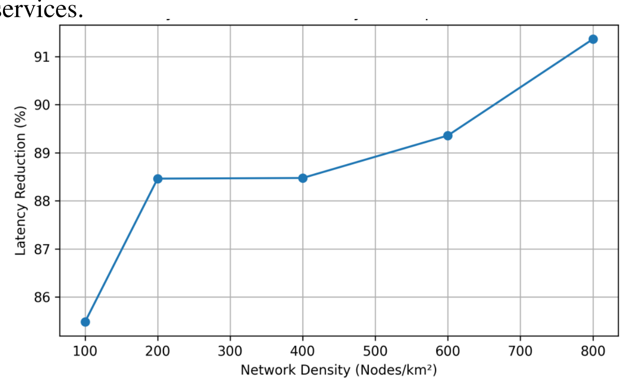

Figure 6: Latency Reduction Achieved by Proposed Framework.

6.2 Packet Loss & Energy Efficiency Analysis

Packet Delivery Ratio (PDR) and Energy Consumption are critical due to the highly dynamic topology of FANETs and the constrained battery life of UAVs and IoT devices. Table 3 depicts the reliability and power metrics comparison of the proposed framework and baseline.

Table 3: Reliability and Power Metrics Comparison

Vehicle Speed (km/h)	Baseline PDR (%)	Proposed Framework PDR (%)	UAV Energy Consumption (Joule/sec)
20	98.2	99.9	12.1
50	94.5	99.5	12.8
80	88.1	98.7	13.5
120	76.4	97.2	14.2
160	61.2	94.8	15.1

Figure 7 depicts comparison of packet delivery ratio (PDR) under high mobility dynamics by comparing proposed 6G FANET-IoT-IoV framework with baseline 5G framework. It is clear from the results that the proposed method performs well under high speed and mobility dynamics while resulting in better PDR as compared to the baseline.

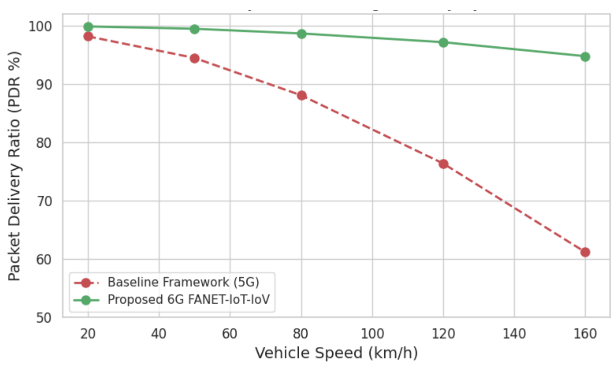

Figure 7: Packet Delivery Ratio under High Mobility Dynamics.

6.3 Resource Allocation & Routing Protocol Optimization

Our paper uses an DRL based optimization for dynamic resource allocation and routing. Below is the convergence and execution efficiency data comparison of different algorithms along with our proposed DRL based Optimization. Table 4 presents comparison of optimization algorithms based on different metrics.

As illustrated in Figure 8, the convergence profile, the proposed DRL-based resource allocation reaches its optimal fitness value within 15 iterations, outperforming Particle Swarm Optimization (PSO) by 76.4% in time-to-convergence. This rapid adjustment allows the FANET-IoV layer to seamlessly handle sudden topological shifts caused by fast-moving vehicles.

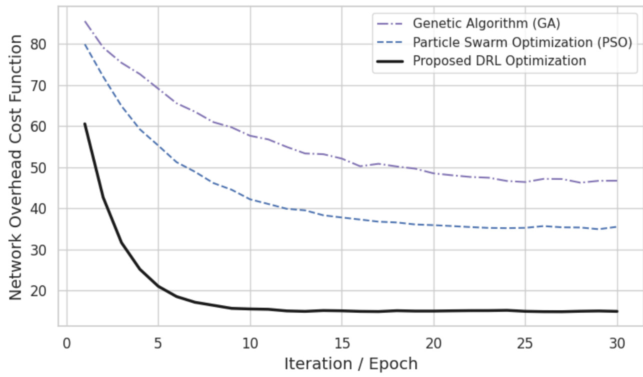

Figure 8: Convergence Profile for Resource Allocation and Routing.

Table 4: Comparison of Optimization Algorithms.

Metric Analyzed	Legacy OSPF /AODV	Genetic Algorithm (GA)	PSO Optimization	Proposed DRL-based Optimization
Convergence Time (s)	N/A	14.2	8.5	1.2
Resource Utilization (%)	48.5%	72.1%	79.4%	94.6%
Routing Overhead (Kbps)	340	210	185	65
Path Re-routing Delay (ms)	120	65	42	8

6.4 QoS Management Optimization

This matrix validates how your framework categorizes and protects critical data streams (e.g., autonomous driving safety alerts vs. environmental smart city IoT data). Table 5 depicts Class performance slicing by comparing different traffic classes.

6.5 Discussion

The integration of FANETs, IoT, and IoV within 6G networks represents a promising yet complex domain for advancing smart city applications. Through an extensive literature review, this research has highlighted significant progress in the field while identifying critical challenges and gaps that remain unaddressed. This discussion synthesizes the key insights gained from existing studies and reflects on the potential implications for future research. A primary finding from the literature is the tremendous potential of combining FANETs, IoT, and IoV to enable smarter, more efficient urban systems. FANETs can extend communication coverage and enable real-time data collection, while IoT facilitates seamless interconnectivity between diverse devices, and IoV enhances intelligent mobility solutions. When empowered by 6G networks, these technologies promise breakthroughs in urban management, including optimized traffic systems, enhanced public safety, and real-time monitoring of infrastructure. However, the review also underscores several recurring challenges.

One major issue is the limited scalability of existing models and algorithms when applied to large-scale urban environments. Most existing studies focus on small scale test scenarios, leaving questions about their effectiveness in real-world deployments. Additionally, energy efficiency emerges as a recurring bottleneck, particularly for FANETs, which are inherently resource-constrained. Current solutions, though innovative, lack the adaptability needed for diverse and dynamic city scenarios. The security and privacy of data flowing through these integrated systems also demand greater attention. While some studies explore blockchain and cryptographic solutions, practical implementations in highly dynamic networks like FANETs remain largely theoretical. Moreover, the interoperability between FANETs, IoT, and IoV technologies poses significant hurdles. Each technology operates on distinct protocols and architectures, and achieving seamless communication requires robust, standardized frameworks. Despite these challenges, the literature points to exciting opportunities.

Table 5: QoS Performance Achieved by the Proposed Network Slicing Framework for Different 6G Service Classes.

Traffic Class	Priority	Guaranteed Bandwidth (Mbps)	Achieved Jitter (ms)	Packet Loss ($\times 10^{-5}$)
URLLC (Ultra-Reliable Low-Latency Communications)	High	500	0.22	0.001
eMBB (Enhanced Mobile Broadband)	Medium	2500	1.45	0.120
mMTC (Massive Machine-Type Communications)	Low	50	4.80	1.050

Advances in AI and machine learning have the potential to revolutionize this domain by enabling adaptive algorithms that dynamically optimize network performance and energy consumption. Similarly, the concept of context-aware systems, which adjust operations based on environmental and user conditions, holds promise for improving resource allocation and efficiency. It is also worth noting the role of 6G networks in addressing many of these issues. With ultra-low latency, higher data rates, and improved connectivity, 6G can provide the infrastructure needed to support the complex interactions between FANETs, IoT devices, and IoV systems. However, the full potential of 6G remains untapped, with much work needed to align its capabilities with the unique demands of these integrated technologies. While this research primarily involves reviewing existing studies, it lays a foundation for future investigations. It identifies several key performance metrics such as network throughput, latency, energy efficiency, and reliability that should guide future evaluations.

Furthermore, it highlights the importance of moving beyond simulations to real-world validation, which is critical for addressing practical constraints and improving the applicability of theoretical models. The scalability of simulation models often falls short of replicating the complexity of real-world urban environments. To address this, we propose a dual approach that integrates both highfidelity simulations and real-world test-beds. This strategy not only enhances the reliability of findings but also provides actionable insights for practical implementations. Additionally, security and privacy concerns emerge as significant barriers to widespread adoption. While the blockchain-based and AIdriven solutions offer promising avenues, further exploration is required to ensure these frameworks are robust against evolving cyber threats. The discussion also highlights the role of collaboration between academia, industry, and government stakeholders in advancing the field. By aligning research objectives with practical urban needs, the integration of FANET-IoT-IoV systems can significantly contribute to smarter, safer, and more sustainable cities.

7 Conclusion

In conclusion, the integration of FANETs, IoT, and IoV within 6G-enabled smart cities not only offers a wide range of possibilities but also presents multifaceted challenges. This research highlights existing methods, identifies areas requiring further exploration, and provides a roadmap for addressing these challenges. By focusing on scalability, security, energy efficiency, and real-world validation, future studies can bridge the gap between current capabilities and the demands of next-generation smart city infrastructures. This is an evolving field with immense potential to shape smarter, safer, and more sustainable urban futures. While this research provides a robust foundation for integrating FANETs, IoT, and IoV within 6G frameworks, it also underscores the need for continuous innovation and interdisciplinary collaboration. The future directions outlined serve as a roadmap for addressing existing challenges and unlocking the full potential of these disruptive technologies in shaping next-generation smart cities.

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Author Contributions

Conceptualization, R.R.; methodology, R.R.; software, R.R.; validation, R.R., F.A., and Z.R.; formal analysis, R.R.; investigation, R.R.; resources, F.A. and Z.R.; data curation, R.R.; writing—original draft preparation, R.R.; writing—review and editing, F.A. and Z.R.; visualization, R.R.; supervision, F.A. and Z.R.; project administration, F.A. and Z.R. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

All the authors declare that they have no conflict of interest.

Data Available

The data and materials used in this study are available from the corresponding author upon reasonable request.

References

[1] Qian, Y., Wu, D., Bao, W., Lorenz, P.: The internet of things for smart cities: Technologies and applications. IEEE Network **33**(2), 4–5 (2019). https://doi.org/10.1109/MNET.2019.8675165

[2] Hamid, U.Z.A., Zamzuri, H., Limbu, D. K.: "Internet of vehicle (IoV) applications in expediting the implementation of smart highway of autonomous vehicle: A survey", in Performability in Internet of Things. Springer, Cham, Switzerland (2019). https://doi.org/10.1007/978-3-319-93557-7_9.

[3] Lucic, M.C., Bouhamed, O., Ghazzai, H., Khanfor, A., Massoud, Y.: Leveraging UAVs to enable dynamic and smart aerial infrastructure for ITS and smart cities: An overview. Drones **7**(2), 79 (2023). https://doi.org/10.3390/drones7020079

[4] Minoli, D., Occhiogrosso, B.: Practical aspects for the integration of 5G networks and IoT applications in smart cities environments. Wireless Communications and Mobile Computing **2019**, 5710834 (2019). https://doi.org/10.1155/2019/5710834

[5] Chandran, I., Vipin, K.: Multi-UAV Networks for Disaster Monitoring: Challenges and Opportunities from a Network Perspective. Drone Systems and Applications **12**, 1–28 (2024). https://doi.org/10.1139/dsa-2023-0079

[6] Bhat, J.R., Alqahtani, S.A.: 6G ecosystem: Current status and future perspective. IEEE Access **9**, 43134–43167 (2021). https://doi.org/10.1109/ACCESS.2021.3054833

[7] Khan, M.A., Kumar, N., Mohsan, S.A.H., Khan, W.U., Nasralla, M.M., Alsharif, M.H., Żywiołek, J., Ullah, I.: Swarm of UAVs for network management in 6G: A technical review. IEEE Transactions on Network and Service Management **20**(1), 741–761 (2022). https://doi.org/10.1109/TNSM.2022.3213370

[8] Prateek, K., Ojha, N.K., Altaf, F., Maity, S.: Quantum secured 6G technology-based applications in Internet of Everything. Telecommunication Systems **82**(2), 315–344 (2023). https://doi.org/10.1007/s11235-022-00979-y

[9] Shrestha, R., Bajracharya, R., Kim, S.: 6G enabled unmanned aerial vehicle traffic management: A perspective. IEEE Access **9**, 91119–91136 (2021). https://doi.org/10.1109/ACCESS.2021.3092039

[10] Houssein, E.H., Othman, M.A., Mohamed, W.M., Younan, M.: Internet of Things in smart cities: Comprehensive review, open issues, and challenges. IEEE Internet of Things Journal **11**(21), 34941–34952 (2024). https://doi.org/10.1109/JIOT.2024.3449753

[11] Ang, L.-M., Seng, K.P., Ijemaru, G.K., Zungeru, A.M.: Deployment of IoV for smart cities: Applications, architecture, and challenges. IEEE Access **7**, 6473–6492 (2019). https://doi.org/10.1109/ACCESS.2018.2887076

[12] Srivastava, A., Prakash, J.: Future FANET with application and enabling techniques: Anatomization and sustainability issues. Computer Science Review **39**, 100359 (2021). https://doi.org/10.1016/j.cosrev.2020.100359

[13] Lakew, D.S., Sa'ad, U., Dao, N.-N., Na, W., Cho, S.: Routing in flying ad hoc networks: A comprehensive survey. IEEE Communications Surveys & Tutorials **22**(2), 1071–1120 (2020). https://doi.org/10.1109/COMST.2020.2982452

[14] Khan, M.A., Qureshi, I.M., Khanzada, F.: A hybrid communication scheme for efficient and low-cost deployment of future flying ad-hoc network (FANET). Drones **3**(1), 16 (2019). https://doi.org/10.3390/drones3010016

[15] Siddiqi, M.H., Draz, U., Ali, A., Iqbal, M., Alruwaili, M., Alhwaiti, Y., Alanazi, S.: FANET: Smart city mobility off to a flying start with self-organized drone-based networks. IET Communications **16**(10), 1209–1217 (2022). https://doi.org/10.1049/cmu2.12291

[16] Raza, R., Aadil, F.: A comprehensive survey on FANET-IoT-IoV interactions: Challenges, opportunities, and future directions in 6G-enabled smart cities. Computing, **108**(1), 10 (2026). https://doi.org/10.1007/s00607-025-01602-z

[17] Cheng, N., Wu, S., Wang, X., Yin, Z., Li, C., Chen, W., Chen, F.: AI for UAV-assisted IoT applications: A comprehensive review. IEEE Internet of Things Journal **10**(16), 14438–14461 (2023). https://doi.org/10.1109/JIOT.2023.3268316

[18] Sharma, S., Popli, R., Singh, S., Chhabra, G., Saini, G.S., Singh, M., Sandhu, A., Sharma, A., Kumar, R.: The role of 6G technologies in advancing smart city applications: opportunities and challenges. Sustainability **16**(16), 7039 (2024). https://doi.org/10.3390/su16167039

[19] Sanjalawe, Y., Fraihat, S., Al-E'Mari, S., Abualhaj, M., Makhadmeh, S., Alzubi, E.: A review of 6G and AI convergence: Enhancing communication networks with artificial intelligence. IEEE Open Journal of the Communications Society **6**, 2308–2355 (2025). https://doi.org/10.1109/OJCOMS.2025.3553302

[20] Maglaras, L.A., Al-Bayatti, A.H., He, Y., Wagner, I., Janicke, H.: Social internet of vehicles for smart cities. Journal of Sensor and Actuator Networks **5**(1), 3 (2016). https://doi.org/10.3390/jsan5010003

[21] Uslu, E.E., Ozturk, B., Gorkemli, B., Soyturk, M., Cihan, S.B., Gunduzhev, A.R., Dagdeviren, O.: Next-generation management and orchestration for 6G: Emerging trends, architectures, and challenges. IEEE Open Journal of the Communications Society **7**, 2222–2269 (2026). https://doi.org/10.1109/OJCOMS.2026.3670073

[22] Liu, B., Shi, H., Jia, D., Wang, E., Han, W., Zhong, K., Wu, L., Chen, S., Qiao, C., Wang, J.: Collaborative sensing and communication for intelligent connected vehicles: A comprehensive survey. IEEE Communications Surveys & Tutorials **28**, 3125–3164 (2026). https://doi.org/10.1109/COMST.2025.3626504

[23] Kuru, K.: Planning the Future of Smart Cities With Swarms of Fully Autonomous Unmanned Aerial Vehicles Using a Novel Framework. IEEE Access **9**, 6571–6595 (2021). https://doi.org/10.1109/ACCESS.2020.3049094

[24] Kumar, A., Ahuja, S., Gupta, G.: "Disaster recovery management in FANETs", In Autonomous Flying Ad-Hoc Networks. Scrivener Publishing, Beverly, MA, USA (2025). https://doi.org/10.1002/9781394231089.ch8

[25] Sharma, M., Singh, M., Walia, K., Kaur, K.: A comprehensive study of performance parameters for MANET, VANET and FANET. In Proceedings of the 2019 IEEE 10th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON), pp. 643–646 (2019). https://doi.org/10.1109/IEMCON.2019.8936159

[26] Yogarayan, S.: Wireless ad hoc network of MANET, VANET, FANET and SANET: A review. Journal of Telecommunication, Electronic and Computer Engineering **13**(4), 13–18 (2021). https://jtec.utem.edu.my/jtec/article/view/6119

[27] Wang, J., Feng, H., Chen, J., Zhou, L., Zhang, M., Jiang, C.: EDP protocol: Advancing mobility-aware drone network connectivity with adaptive routing. IEEE/ACM Transactions on Networking **34**, 2242–2255 (2026). https://doi.org/10.1109/TNET.2025.3556421

[28] Uddin, S., Shah, A.F.M.S., Karabulut, M.A., Ilhan, H.: Cooperative MAC protocol with optimal relay selection algorithm for UAVs ad hoc network in disasters. IEEE Transactions on Vehicular Technology **74**(9), 14445–14456 (2025). https://doi.org/10.1109/TVT.2025.3558455

[29] Raza, R., Zahoor-ur-Rehman, Naeem, M., Aadil, F., Shehzad, F., Coronato, A.: A hybrid cognitive radio and multi-agent reinforcement learning framework for jamming resilience in integrated FANET-IoT-IoV systems. Automation, **7**(4), 108 (2026). https://doi.org/10.3390/automation7040108

[30] González-Zamar, M.-D., Abad-Segura, E., Vázquez-Cano, E., López-Meneses, E.: IoT technology applications-based smart cities: Research analysis. Electronics **9**(8), 1246 (2020). https://doi.org/10.3390/electronics9081246

[31] Razmjoo, A., Gandomi, A., Mahlooji, M., Astiaso Garcia, D., Mirjalili, S., Rezvani, A., Ahmadzadeh, S., Memon, S.: An investigation of the policies and crucial sectors of smart cities based on IoT application. Applied Sciences **12**(5), 2672 (2022). https://doi.org/10.3390/app12052672

[32] Karabulut, M.A., Shah, A.F.M., Pathan, A.-S.K., Bradford, P.G.: IoT-driven intelligent transportation system in the era of 6G and AI: A review. Computers, Materials & Continua **88**(1), 1. (2026). https://doi.org/10.32604/cmc.2026.077625

[33] Kaginalkar, A., Kumar, S., Gargava, P., Niyogi, D.: Review of urban computing in air quality management as smart city service: An integrated IoT, AI, and cloud technology perspective. Urban Climate **39**, 100972 (2021). https://doi.org/10.1016/j.uclim.2021.100972

[34] Laha, S.R., Pattanayak, B.K., Pattnaik, S.: Advancement of environmental monitoring system using IoT and sensor: A comprehensive analysis. AIMS Environmental Science **9**(6), 771–800 (2022). https://doi.org/10.3934/environsci.2022044

[35] Saleem, M.U., Usman, M.R., Usman, M.A., Politis, C.: Design, deployment and performance evaluation of an IoT based smart energy management system for demand side management in smart grid. IEEE Access **10**, 15261–15278 (2022). https://doi.org/10.1109/ACCESS.2022.3147484

[36] Slany, V., Krcalova, E., Balej, J., Zach, M., Kucova, T., Prauzek, M., Martinek, R.: Smart water-IoT: Harnessing IoT and AI for efficient water management. ACM Computing Surveys **57**(12), 1–36 (2025). https://doi.org/10.1145/374433

[37] Ijemaru, G.K., Ang, L.M., Seng, K.P.: Transformation from IoT to IoV for waste management in smart cities. Journal of Network and Computer Applications **204**, 103393 (2022). https://doi.org/10.1016/j.jnca.2022.103393

[38] Zhang, H., Zhang, R., Sun, J.: Developing real-time IoT-based public safety alert and emergency response systems. Scientific Reports **15**, 29056 (2025). https://doi.org/10.1038/s41598-025-13465-7

[39] He, Q., Lin, J., Fang, H., Wang, X., Huang, M., Yi, X., Yu, K.: Integrating IoT and 6G: Applications of edge intelligence, challenges, and future directions. IEEE Transactions on Services Computing **18**(4), 2471-–2488 (2025). https://doi.org/10.1109/TSC.2025.3586152

[40] Das, R., Zhou, L., Bi, S., Wang, T., Hou, T.: Towards the safety of intelligent transportation: A survey on the security challenges and mitigations in Internet of Vehicles (IoV). ACM Transactions on Sensor Networks, **22**(3), 1–44 (2026). https://doi.org/10.1145/3786592

[41] Brito, O.D.D., Campoverde, L.M.S., Tropea, M., Rango, F.D.: Environmental monitoring in smart cities: An energy-aware analysis on an IoV scenario. In Proceedings of the 2025 IEEE Symposium on Computers and Communications (ISCC), pp. 1–6 (2025). https://doi.org/10.1109/ISCC65549.2025.11326339

[42] Sedaghat, S., Conti, M.: CFEA-IoV: An SDN-enabled IoV architecture for time-critical accident notification in automated vehicles. IEEE Transactions on Intelligent Vehicles **10**(2), 752–761 (2025). https://doi.org/10.1109/TIV.2024.3418307

[43] Zhang, X., Li, J., Zhou, J., Zhang, S., Wang, J., Yuan, Y., Liu, J., Li, J.: Vehicle-to-everything communication

in intelligent connected vehicles: A survey and taxonomy. Automotive Innovation, **8**(1), 13–45 (2025). https://doi.org/10.1007/s42154-024-00310-2

[44] Tan, K., Zhu, C.: Multimodal sensing for intelligent V2X: A review of recent advances toward deployment. IEEE Internet of Things Journal **12**(22), 46294–46315 (2025). https://doi.org/10.1109/JIOT.2025.3601236

[45] Rodríguez-Piñeiro, J., Wei, Z., Wang, J., Gutiérrez, C.A., Correia, L.M.: 6G-enabled vehicle-to-everything communications: Current research trends and open challenges. IEEE Open Journal of Vehicular Technology **6**, 2358–2391 (2025). https://doi.org/10.1109/OJVT.2025.3599570