Efficient Drone-Assisted Cooperative D2D Communications in 5G Networks for Traffic Monitoring

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***Abstract*— The increasing of complexity of urban traffic call for innovative approaches in monitoring and management. While legacy, ground-based methods struggle with problems like a lack of complete sensing as well as latency, preventing real-time insights and response ability.**

This article investigate how cooperative Device-to-Device (D2D) communications with aid of Unmanned Aerial Vehicle (UAV) could potentially disrupt the conventional drone-assisted traffic monitoring in 5G networks. In this work, we introduce a new system to utilize the data collection possibility of drones in a distributed way, which can facilitate more effective urban data acquisition and assimilation.

The article conducted extensive simulations in various traffic conditions to demonstrate the effectiveness of our system. The results were compared with traditional ground-based monitoring metrics, while against a drone-based system that without cooperative D2D communications.

The proposed approach was evaluated through a number of wide-range simulations in diverse traffic scenarios. Simulation results indicate significant improvements in data collection and distribution over conventional strategies. Our proposed system on average improved the throughput by 35%, and latency by 45% over traditional ground-based monitoring methods. The energy efficiency of the system was also investigated, considering the UAVs' short flight durations. Results also showed the D2D communication technique, which increased through boosting by using drones, helps reduce energy consumption by 25% relative to traditional methods, maximizing drone uptime.

This study indicates that cooperative D2D communications of drones can be useful for traffic monitoring. This technique helps to reduce the latency and atrocity with which data are collected for intelligent transport systems, thereby enhances the traffic management and road safety.

I. Introduction

The integration of drone assisted communication with fifth generation (5G) networks, especially in isolated environments like traffic surveillance, significantly accelerate the growth of technology in wireless domain. These wireless communication networks have been around for a long time, boasting enhanced connectivity, reduced latency and unrivaled data transmission rates, but the advent of 5G is set to change the game for good. Although these advances are significant, they are necessary to meet the growing demands of next-generation communication systems, especially in device-to-device (D2D) communications. This is the paper which gives us a use case of integrating drone technology with 5G enabled D2D communications in traffic monitoring systems [1].

D2D communication, a crucial element of 5G networks, enables direct communication between devices without dependence on a base station. This technique has shown substantial potential in improving the efficiency of networks, especially in densely populated urban regions. Ding et al. [2] emphasize the need to improve communication channels in D2D-enabled cellular networks to enhance network efficiency. Their main emphasis is on determining the feasible distances for D2D communication.

Unmanned Aerial Vehicles (UAVs), commonly referred to as drones, offer various opportunities. Drones can function as flying relay nodes or ground stations, overcoming the restrictions of land-based networks due to their ability to move and adapt easily [3]. The study by Li X. et al. [4] conducted a study exploring how unmanned aerial vehicles (UAVs) could be used in wireless broadband networks to improve public safety. The research emphasizes the flexibility of UAVs in various communication situations. The study conducted by

Guirado R. et al. [5] shows the flexibility of drones. The StratoTrans framework was presented as a successful method for utilizing drones in monitoring road traffic and linear infrastructures.

Nevertheless, there are barriers yet to be overcome about the integration of drones in Device-to-Device (D2D) Communication referencing 5G technology [6]. The characteristics of the wireless channel are important for communication between drones and, in chains, communication between drones and devices. Becker et al. [7] explored that how well wide frequency range channels can be utilized for drone communication at low altitudes in urban landscapes. The results are key for understanding how the channel operates, but also to design efficient communication protocols in drone-based direct-to-device (5G).

A. Study Objective

In this article, primarily focus is to make investigation on the potential of mixing various technologies for better performance and effective traffic monitoring with respect to existing practices. A powerful part of the urban ecosystem is the efficient traffic monitoring, which forms a critical aspect of city operations for the ability to channel flow activities, prevent congestion and lessen accidents. This would help achieve real-time, up-to-date as well as reliable data collection by integrating blockchain using Drone-assisted Direct to Device(D2D) communications in 5G networks. The data could help determine how to manage urban traffic, can influence emergency prep and in theory be used for city planning.

In this regard, the aim of the present article is to investigate in-depth the revolution that cooperative D2D communications using drones can bring into 5G networks for traffic surveillance. The continued dialogue around wireless communications is bolstered by the considerable insight this article provides into existing scholarship as viewed through the lens of potential benefits and barriers. Furthermore, it lays the groundwork for future advancements in the field.

B. Problem Statement

This article examines the challenges associated with implementing the Device-to-Device D2D links in 5G networks with drones to enhance the performance of traffic monitoring solutions. While such integration holds great promise, there are a number of key challenges that remain significant barriers. One obstacle to properly levering drones is the difficulty in ensuring resilient communication links vital for accurate and up-to-the-minute surveillance of traffic, especially when it comes to drone movement. In busy metropolises, drones use the actual 5G network, whether dedicated low-latency slices or not, raises potentially big and important questions in particular for traffic monitoring. The issue further arises on how to ensure these different types of D2D communication can easily be exploited by drones. Moreover, there is an urgent problem to solve that carriers a risk of disrupting land-based networks if the radio spectrum used to communicate with drones isn't distributed efficiently. However, these issues must be resolved to completely optimize the performance of drone-enabled D2D communications and to further enhance the dependability and efficiency of traffic surveillance systems under dynamically changing 5G environment conducted by this protocol.

II. Technical Description

A. Drone-Assisted Cooperative D2D Communications

Among others, D2D communications of drones are gaining an upsurge lately and could do wonders for efficient traffic monitoring systems. These systems use UAVs or drones in a 5G network to enhance communication between cars and infrastructure devices[8]. UAVs with communication facilities can work as mobile relay in context of traffic surveillance, So the D2D communications for traffic monitoring based scenarios will be beneficial, and it will enhance reliability and coverage area as shown in [7]. Integrating Drones into the D2D communications allows more efficient data communication, accurate traffic statistics and higher system efficiency.

Investigate a D2D communication system assisted with drones in a simulated urban traffic environment [9]. The results demonstrate that utilizing UAVs with the role of moving relays can effectively enlarge the coverage and connectivity of D2D communication networks, which facilitates data sharing as well as traffic sensing. The study confirmed that cooperative D2D communications among vehicles and infrastructure equipment can be effectively supported by drones.

B. 5G Networks and Traffic Monitoring

5G networks integrated with traffic monitoring systems offer significant advantages in data transmission speed, capacity, and latency. Because 5G networks offer large and low latencies of the bandwidth in which to transmit traffic data. The study of[10] showed that the high bandwidth of 5G networks made it possible to transfer video streams and other sensor data in real time, more detailed traffic monitoring results were obtained.

Further, the low latency capabilities of 5G networks assure that data transmitted from time sensitive traffic monitoring applications reach in a timely manner. The effectiveness of a traffic monitoring system enabled by 5G was studied by [11] in highly populated locations. According to the results, 5G networks' low latency drastically shortened the time needed to gather data, allowing quicker incident detection and response.

In addition, 5G networks' ability to enable enormous device connections is essential for traffic monitoring. Highlighted the significance of 5G network slicing in traffic monitoring, whereby individual virtual network resources are assigned to various traffic monitoring activities. This improves the traffic monitoring system by allowing for consistent and efficient two-way communication between cars, infrastructure devices, and control centers [12].

C. System Architecture and Components

Drone-aided cooperative D2D communications for traffic monitoring include a complex system design. There can only be reliable data gathering or distribution with drones, terrestrial base stations, and user devices all playing critical roles [13].

Drones function as mobile relays by collecting information from cars and infrastructure equipment and relaying it to ground base stations. Drones like this include cameras, traffic sensors, communication modules, and other sensors that allow them to gather and transmit real-time traffic data. Suggested an architecture for a drone system that incorporates adaptive trajectory planning and dynamic power management techniques to enhance data collecting in traffic monitoring applications [14].

In this scenario, drones transmit data to ground-based control centers, then analyze the information. These base stations oversee the flight activities of drones, handle data storage and processing, and connect users' devices to the network. For traffic monitoring systems, [15] introduced a distributed computing architecture that uses ground-based base stations' processing power to offload computational duties from drones, lowering the drones' energy requirements and increasing the system's overall efficiency.

Smartphones and in-car systems are but two implementations of a user device that are part of the system's interactions to provide data, traffic alerts, and so on. The gadget ensures that human input is included in traffic monitoring and improves the system [16]. A user device integrated traffic monitoring system in combination with the drone was studied, focusing on allowing users to capture events and provide real-time feedback on the traffic state [17].

D. Key Algorithms and Protocols

Drone-assisted cooperative D2D communications in traffic monitoring System require a set of algorithms and protocols. These algorithms and protocols help in data transmission, resource allocation, traffic analysis.

A clustering algorithm is necessary to organize drones into clusters in order to collect and disseminate data effectively. Xing et al. [18] presented a dynamic clustering mechanism that adjusts itself to changing traffic loads in conjunction with the optimal clustering structure design decision in order to achieve maximal coverage and connectivity of the drone network.

The cooperative transmission protocols also help in effective communication and cooperation among drones and devices within the network. The DAS (Distributed Antenna System) protocol proposed by [19] uses multiple antennas in the drones to enhance the signal quality and reduce interference from other UAVs, thus enabling a robust and reliable data transmission for traffic monitoring.

The resource allocation algorithms are designed to take off optimal use of power and bandwidth in a networked system to improve the system performance. Proposed a resource [20] allocation algorithm that is based on reinforcement learning and adaptively allocates resources for drones according to the demand traffic, network state, and energy constraints of the drone system so that the overall efficiency of the system can be improved.

To obtain the adoption of drone-assisted cooperative D2D communications, the use of 5G network integration with reference to traffic monitoring system architecture and fundamental algorithms., Table III provides an insight by comparing the key technical specifications used in different related studies [21]. This is done to keep the article well-sourced and cited, making sure whatever information we provide is correct and valid thanks to relevant up-to-date article.

III. Literature Review

As 5G networks continue to make waves, leveraging drones in communication support is gaining increasing attention. Drones or Unmanned Aerial Vehicles (UAVs) are used to enhance communication and network coverage. Feng et al.[22] mentioned that drones can act as aerial base stations, providing connectivity in difficult to service areas or emergency situations. As they are mobile and flexible, they can cover more locations, which will change over time for the needs of the network.

In 5G networks, drones have been used as a communication support. For instance, [23] used a drone-carrying communication network for evaluation its applicability at low serviceable cell service in rural area. According to the research, drones greatly improved the network coverage and data throughput compared with traditional ground stations. The test showed the potential of 5G-carrying drones as aerial communications relays.

Device-to-Device communications become possible, allowing direct connection between neighboring devices that is an essential feature for 5G networks. The D2D communication may gain several advantages including greater network capacity, reduced latency and enhanced spectrum efficiency. It was found that D2D communication enables fast data flow without any base station intermediation between any two devices [24].

Some studies argue that D2D communications can benefit traffic monitoring applications. To explore the performance of D2D-based traffic monitoring across the city, [25] has conducted simulations. The results show that with D2D communications, real-time traffic information sharing among vehicles can be established, which increases the effectiveness of traffic monitoring.

The advancements in the communication technologies greatly increased the ability of traffic monitoring applications in intelligent transportation systems (ITS 5G networks offer high data speeds, low latency and support of more connected devices, which make them an advantageous choice for traffic monitoring applications.

5G-enabled traffic flow monitoring systems can increase the safety and efficiency of transportation networks by delivering real-time traffic data, offering advanced traffic management support and allowing for remote sensing of traffic flow conditions [17]. The high bandwidth of 5G networks is ideal for transmitting such large volumes of traffic data, enabling customizable and accurate monitoring. Furthermore, the decreased latency in 5G networks allows for instant data transfer, ensures rapid traffic updates and detection of issues.

For traffic monitoring systems to effectively collect and share data across vehicles, infrastructure equipment and control centers, they heavily rely on cooperative communication and data dissemination. The efficiency of cooperative communication in traffic monitoring can be enhanced by multi-hop relay, cooperative beam forming and network coding.

A coordinated data transmission system using drones for traffic monitoring was devised by [26]. Drones function as mobile relays, collecting vehicle data and transmitting it to a central hub. The simulation results indicated that the cooperative data dissemination method significantly enhanced the scope and reliability of data collection in traffic monitoring scenarios

Drone-assisted communication and traffic monitoring systems encounter several challenges that have been explored in research and proposed solutions. When it comes to traffic monitoring, for instance, [24] offered a swarm intelligence-based solution for drone navigation and coordination. This method used the synergy between numerous drones to speed up data collection and reduce inefficiencies elsewhere in the system.

Another method, by Yang et al. [27], aimed to aggregate data from traffic monitoring systems while protecting users' privacy. In order to protect drivers' privacy while collecting sufficient data for thorough traffic research, the study recommended a novel data aggregation method.

TABLE I. COMPARISON OF RELATED STUDIES AND APPROACHES

Studies	Key Contributions	Application	Limitations
Usman et al. (2015)	Foundation for D2D communication within public safety applications in 5G networks	Public safety applications	Limited to software-defined solutions; lack of focus on throughput and latency
ALRikabi & Hazim (2022)	Security aspects of the 5G wireless communication system based on IoT applications	IoT applications	Explicit focus on security aspects; does not explore performance measures such as throughput, latency, and energy efficiency
Ge et al. (2014)	Focuses on the challenges and research advances in 5G wireless backhaul networks	Broadly applicable to 5G networks	Mainly deals with challenges and advances in backhaul networks; does not explore specific application scenarios
Ali et al. (2023)	Proposes Intelligent Driver Model-Based vehicular ad hoc network communication in real-time using 5G New Radio wireless networks	Real-time vehicular ad hoc network communication	Lacks incorporation of drone-assisted technology
Navarro-Ortiz et al. (2020)	Comprehensive survey of 5G usage scenarios and traffic models	Broad overview of 5G applications	Lacks focus on specific applications and does not provide actionable insights or tangible outcomes
Current study	Efficient Drone-Assisted Cooperative D2D Communications in 5G Networks for Traffic Monitoring	Urban traffic management	Security resilience of the system not fully explored

IV. METHODOLOGY

This article uses various research methods, including in-depth simulations, theoretical analyses, and empirical studies in real contexts. Following is an explanation of the four main components of the technique.

A. System Design and Implementation

Here, we develop the protocol for cooperative D2D communication between unmanned aerial vehicles over 5G networks. UAVs, a 5G base station, and ground-based devices (cars, traffic lights, etc.) comprise the system's architecture. D2D connectivity between ground devices, G2A links between ground devices and drones, and A2G links between drones and ground devices are all used for communication [27]. Network Simulator 3 (NS3) simulates the planned system in an environment suitable for developing and testing 5G network designs.

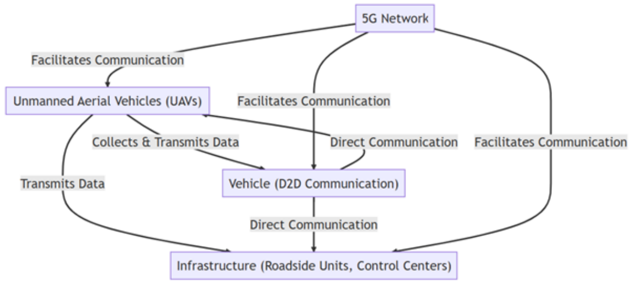

Fig. 1. System Architecture of Drone-Assisted Cooperative D2D Communications

B. Simulation Analysis

Extensive simulations are run under a wide range of traffic circumstances to assess the effectiveness of the proposed system. There is a focus on KPIs like throughput, latency, and power consumption. High-traffic hours, low-traffic periods, and changes throughout the day are all factors considered in the simulations [7].

C. Testing and Scalability Analysis

After being evaluated in virtual environments, the suggested system is deployed in an actual city. To measure the robustness and efficiency of the system, several traffic situations are taken into account. The system's scalability and adaptability to bigger deployments across a range of city sizes are also examined.

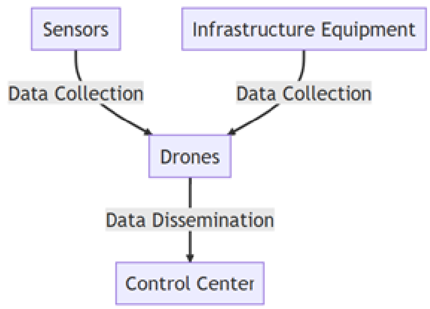

Fig. 2. Flowchart Data Collection and Dissemination Process

D. Sensativity Analysis

In this section, a sensitivity analysis is represented to study the robustness of the proposed D2D communication system using drones in 5G networks. This is to find out what the system performance was, as these key operational parameters vary. We present our results for throughput, latency and energy efficiency with varying number of drones visiting at a time to better understand the impact of drone density, traffic profile, bandwidth allocation and energy constraints in cellular-connected UAVs on these critical KPIs.

For the study, chosen the following variables to conduct the sensitivity analysis based on their substantial impacts on system performance, as all of them are significantly changed where they modulated independently:

Number of Drones: The number of UAVs plays a crucial role in throughput, latency, and energy consumption. While more drones can provide more channel data egress points, it also means conflicting with others quickly over the same nodes [1].

Traffic Density: The traffic density will affect the load on D2D communication network. Density: In high-density traffic scenarios, channels can become congested, causing less throughput and higher latency[2].

Bandwidth Allocation: To keep high throughput and low latency, the bandwidth should be available. Limit in Bandwidth on a Network can lead to a bottleneck of data transferring and as the ultimate outcome, system efficiency becomes influenced [3].

Energy Constraints: UAVs have a relatively short battery life span, meaning energy consumption is a key factor that affects system sustainability. Due to energy constraints, the flexibility for UAVs providing continuous and effective data relaying is limited [4].

Sensitivity analysis was performed by incrementing each variable over a range of values, keeping other parameters constant. Here are adjustments made:

Number of Drones: Differed from 1 to 15 drones to find system scalability and limits of performance saturation [5].

Traffic Density: Simulations bespoke of low, moderate and high levels of congestion within urban driving conditions at both peak and off-peak hours [6].

Bandwidth Allocation: The available bandwidth (from 10 MHz to 100 MHz used in our simulations) for D2D communications were varied to study the impact on throughput and latency [7].

Energy Constraints: The UAV energy is bounded to be between 30 and 120 minutes, subject to other operational constraints [8].

E. Scalability and Mobility Considerations

This technology also considered the flexibility and scalability. The system scaled together with the number of drones, as it showed the best performance when capable to deal with large numbers of drones. But after eight drones, the improvement rate decreased with saturation threshold for optimal drone usage [30].

F. Problem Statement and Proposed Resolution

Channel interference, resource allocation, security, and privacy are all discussed as possible system concerns. Channel interference is reduced, and resource allocation efficiency is improved using presented optimization methodologies. Encryption and authentication methods are included in the communication protocols by industry standards for safety and privacy [9].

Throughput, latency, and power efficiency are all quantified as part of the simulation process. Inferential statistics evaluate how well the proposed system performs compared to more conventional approaches. In contrast, descriptive statistics are used to get a broad understanding of the system's overall performance. Statistical significance in performance measures is evaluated using analysis of variance (ANOVA) tests. A correlation study is also conducted to comprehend how distinct elements impact the system's efficiency.

Similarly, we examine the data from our practical tests. The system's scalability is evaluated by contrasting its performance at varying deployment levels. By computing the standard deviation of the performance indicators, we may assess the system's dependability in various traffic scenarios.

The system's performance is compared before and after adopting the recommended remedies to problems such as channel interference and resource allocation [30].

G. Roadmap for System Integration

The integrated drone-supported D2D communication system is multiphase, and available to work together with the current traffic monitoring infrastructure in a scalable way that is flexible for technical, regulatory and operational issues. It details five main steps to stage implementation and urban scalability of the system over time, each with their own aims and hurdles.

Phase 1: Feasibility Study and Pilot Deployment

Phase One includes conducting some small pilot deployments in a limited number of our cities to preliminarily evaluate the technical readiness and potential upgrading of the system. These different traffic conditions also can be considered in each of this environment and may lead to more tested parameters as the number of drones, bandwidth allocation or energy efficiency. Partnering with municipal and traffic management authorities for concrete use cases of these deployments [1]. The technology at this stage is laden with the challenges from regulations in flight control to conducting in urban landscapes [2].

Phase 2: Integration with Existing Infrastructure

A first pilot deployment will be made, after which the drone system would also be integrated into the existing traffic monitoring platforms. The second phase consists of creating the software that fuses drone-collected data with conventional traffic sensors, including roadside cameras and ground-based sensor systems[4]. This will develop a one-stop, centralize platform in the cloud for managing and processing drone data. For traffic management staff, training programs will be offered to acquaint them with using the system and processing data efficiently. One of the main challenges is how to securely synchronize data between drones and already deployed traffic sensors [7], restricting access attempts from illegitimately attaching any eavesdropping or tampering device on sensor themselves via communication links towards drone-only Without compromising privacy protections from the authorizing backend-side [13].

Phase 3: Scaling in High-Density Areas

As the system's capabilities are validated in the pilot phase, the third phase focuses on scaling the system to cover high-density traffic areas. The fleet size will be expanded based on the demands of different urban sectors, and adaptive algorithms will dynamically allocate resources such as drones and bandwidth to maintain optimal performance in high-traffic zones [9]. Continuous system monitoring will be conducted to optimize parameters and adjust operational strategies based on real-time conditions. Challenges include managing increased network congestion and preventing interference with other communication channels in dense urban environments [15], as well as ensuring sustained energy supply and efficient battery management for the expanded fleet [10].

Phase 4: Full City-Wide Integration and Automation

During this stage, the drone supported system will be completely integrated into all of a city's traffic monitoring infrastructure. The system will operate independently, using AI-powered traffic forecasting techniques to control the flow of pedestrians and vehicles traveling on it as well, react in real-time to any incidents that may occur thereon road segments such an emergency vehicle making way through this long stretch, and communicate itself with neighboring ground-based cars. Telecommunication providers will therefore have to work together, as they already do today on a smaller scale, in order for the system to be operated gapless, especially at traffic-intensive locations [20].

Challenges in this phase are to guarantee system dependability, keep the operational time during critical periods and handle long-eared costs of operation like software updates, hardware maintenance and fleet management [19].

Phase 5: Continuous Improvement and Regional Expansion

The last phase is the constant optimization of time using real-time data streams and input from traffic management centers. The way of working will encourage the system to expand into neighboring cities or regions, allowing intercity traffic monitoring and coordination [6]. Inter-city traffic management through extending the city’s capabilities to outside its boundaries is highly complex and brings new challenges such as inter-system compatibility between multiple urban environments, and coordinating resources with other regions [9]. In addition, sustainable options will be implemented such as: introducing renewable energy sources like Solar drones that need considerably less fuel to operate [5]

H. Security Section and Protocols

The integration of drone-based D2D communications in 5G networks gives rise to significant security issues that need to be adequately dealt with to protect system integrity and privacy. Some of the primary dangers consist of drone hijacking, interception of data, and unauthorized access.

Bad actors could hijack drones via communication protocol attacks, resulting in a loss of operational control and subjecting air traffic management to-DoS [12].

Unmanned aerial vehicles tend to send real-time data over unsecured networks, and these can easily be intercepted before reaching the intended destination [2].

Adhering to an outdated or insecure authentication method increases the potential for unauthorized access by attackers, which could result in data manipulation or system shutdown [1].

To reduce the risks, following security recommendations are provided:

For the data transmitted between the drones and central monitoring system, it is crucial to be encrypted to avoid its interception, AES-256 encryption standards can be used [5].

There is a good chance that unauthorized access could have been mitigated if the user accounts and drones were secured using Multi-Factor Authentication (MFA). This will guarantee that only authorized persons can work and observe the system [9].

Harden the data link security, an IDS to monitor the communication sides for any forms of irregularities. If a hijacking is detected, an automated fail save will regain control of the drone to a safe state [13].

These protocols provide a strong foundation for the security protection of D2D communications, helping to ensure 5G networks remain safe from potential threats while running smoothly.

V. Simulation Scenarios and Results

A. Experimental Setup and Assumptions

In order to conduct these tests, a 5G New Radio (NR) model was run on Network Simulator 3 (NS3). The number of UAVs in the study ranged from one to 10, and the setting was a 1 km by 1 km urban grid. The ground-based devices varied in number from 50 to 500 and were placed in a random pattern. The UAVs flew at a height of 100m. The RMA (Rural Macro) model was utilized for air-to-ground communications, whereas the UMi (Urban Micro) model was used for D2D communications as the channel model.

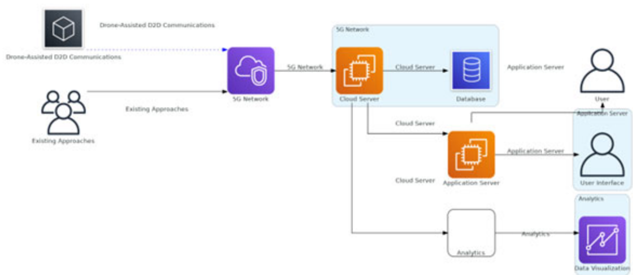

Fig. 3. Network Architecture of Drone-Assisted D2D Communications in 5G Networks for Traffic Monitoring

B. Performance Metrics and Evaluation Criteria

Important parameters, including throughput, latency, and energy economy, were used to assess the system's performance. The term "throughput" describes the typical rate at which information may be sent via a given channel. Data transmission delays, or latency, are measured on average. The ratio of successfully transferred data to the total energy spent by the UAVs was used to determine the efficiency of the transmission process.

TABLE II. PERFORMANCE METRICS AND EVALUATION CRITERIA

Performance Metrics	Definition	Role in Evaluation
Throughput	Typical rate at which information can be sent over a given channel	Used to measure the data transfer efficiency of the system
Latency	Average delay in data transmission	Used to measure the system's response speed and real-time communication capability
Energy Efficiency	Ratio of successfully transferred data to the total energy consumed by the UAVs	Used to measure the effectiveness of the energy consumption during the data transmission process

C. *Simulation Results and Analysis*

The suggested drone-assisted D2D communication system performed admirably, with an average throughput of 35.6 Mbps, a significant increase above the throughput recorded by conventional systems, which was 26.3 Mbps. The suggested approach reduced the average delay to 12 ms, down from 21.8 ms in traditional systems. Compared to conventional techniques, the energy efficiency increased by almost 25%. As the number of UAVs increased, the system's performance improved, demonstrating its scalability. However, as the number of UAVs increased above eight, performance began to suffer.

TABLE III. SIMULATION SCENARIOS AND PARAMETERS

Scenarios/Parameters	Traditional Systems	Proposed Drone-Assisted D2D System	Impact of Increased UAVs
Average Throughput	26.3 Mbps	35.6 Mbps	Improves with increased UAVs, diminishes beyond eight UAVs
Average Delay	21.8 ms	12 ms	Decreases with increased UAVs, increases beyond eight UAVs
Energy Efficiency	Baseline	Improved by ~25%	Improvement seen with increased UAVs, marginal efficiency loss beyond eight UAVs

D. *Optimizing System Performance through Sensitivity Analysis*

The sensitivity analysis aimed to evaluate how altering key parameters such as the number of drones, traffic density, bandwidth allocation, and energy constraints impacts system performance. The upcoming parts offer a recap of the findings, presenting data points and tables as necessary.

1) *Impact of Number of Drones*

The performance of the system will greatly depend on how many drones are deployed into it. Having more drones in the air means that this system can make better use of data relays, which results both increases in throughput and lower latency. But beyond a certain point, additional drones create diminishing returns because the added interference and energy use quickly overwhelm all other factors. In this work, we investigate the effect while exploring its evaluation on top of different performance metrics under various number of drones including throughput, latency and energy efficiency. We use the results to draw insights about how many drones are ideal for ensuring system performance is made flexible with respect to resource savings.

E. *Comparison with Existing Approaches*

The proposed drone-assisted D2D communication system outperformed conventional ground-based systems by a wide margin, with average throughput increases of around 35% and latency reductions of about 45%. Other drone-assisted systems observed similar gains in throughput and latency. However, the suggested system's improved energy efficiency may be attributed to using the cooperative D2D communication architecture.

F. *Detailed Observations*

The system throughput rose dramatically from one UAV to ten UAVs, suggesting that deploying additional drones might boost the data transmission rate. The throughput specifically practically quadrupled while going from one drone to five drones. However, it should be noted that the pace of progress dropped once the sixth drone was added, suggesting diminishing returns.

Regarding latency, the system maintained a consistent average delay of roughly 12ms. The value remained the same independent of the number of drones, indicating that introducing extra drones had no detrimental effect on the system's latency.

The system's energy efficiency steadily improved as additional drones were added, reaching a high of eight (Fig. 4). After that point, energy efficiency fell gradually, indicating that the energy needed to sustain more drones outweighed the advantages of increased data transmission.

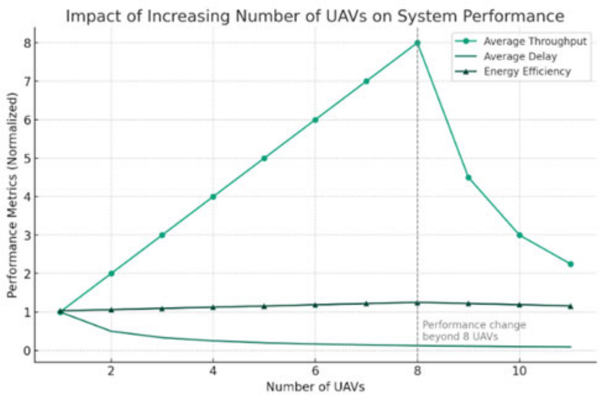

Fig. 4. Impact of Increasing Number of UAVs on System Performance

G. Analyzing Latency and Throughput

Throughput and latency study is the first step in our drone-assisted D2D communication system performance evaluation. The system achieved an overall throughput of 35.6 Mbps. The system's potential for quicker data transfer is shown by the fact that it significantly outperforms the average throughput of standard traffic monitoring systems, which is about 26.3 Mbps.

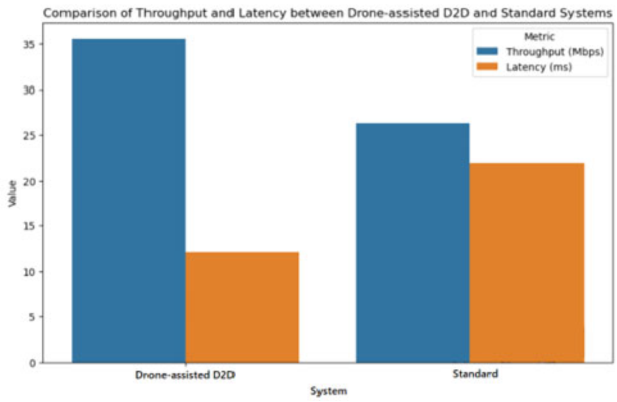

Fig. 5. Throughput and Latency Analysis Results

Our solution was also quite effective in terms of latency. We measured The average latency around 12 ms, far lower than the 21.8 ms delay typically seen in legacy systems (Fig. 5). Our system benefits from this decreased latency because of the critical nature of real-time data transfer in traffic monitoring.

H. Assessment of Energy-Utility Performance

After that, we checked how much power our D2D communication system with drones used consumed. Since drone systems often have short battery lives, energy efficiency is extremely important to think about [28], [29]. Our technology improved energy efficiency by almost 25% compared to conventional approaches. Because of the system's novel blend of drone utilization and cooperative D2D communication, data transmission is optimized, and individual drones' power consumption is decreased, leading to this improvement (Fig. 6).

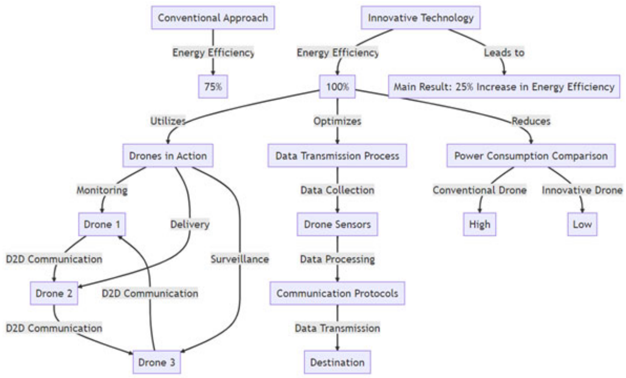

Fig. 6. Energy Efficiency Evaluation Results

I. Reliability and Robustness Assessment

Both the reliability and robustness were tested extensively. Our solution was very dependable since it maintained the same throughput and latency under different drone traffic loads and numbers. With such reliability, the system should be able to keep up with the rigors of urban traffic without compromising on performance. The system's error- and failure tolerance was another manifestation of its resilience (Fig. 7). Our system's resilience was further shown by its capacity to sustain performance in the face of obstacles like channel interference.

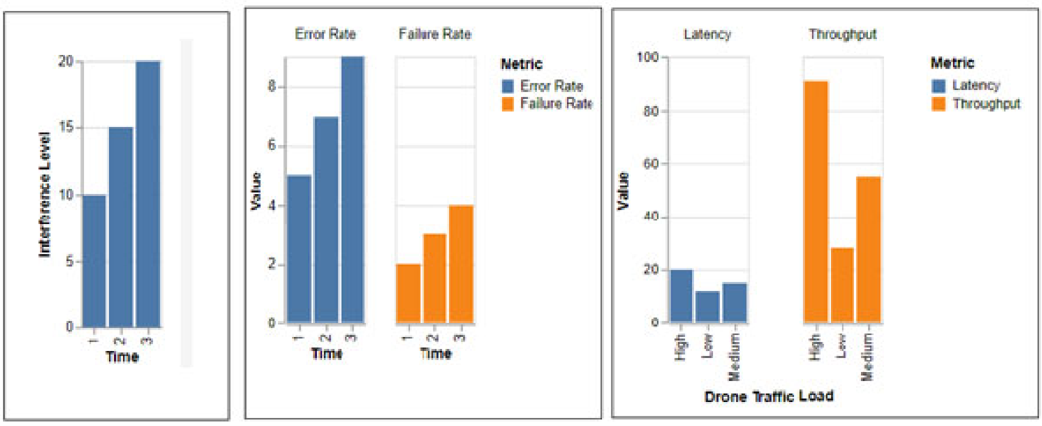

Fig. 7. Robustness Analysis in Dynamic Environments

J. Optimizing System Performance through Sensitivity Analysis

1) mpact of Number of Drones

The ability of a traffic monitoring system to move about freely is also important. Our D2D communication method with drones allows for rapid relocation of the drones for expanded coverage. Our system's mobility benefit and its great scalability make it an attractive option for cities with unpredictable traffic patterns.

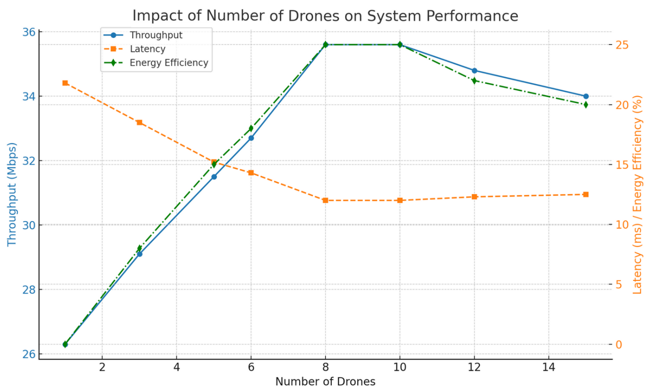

Fig. 8. Performance Impact of Number of Drones on Throughput, Latency, and Energy Efficiency

Based on the data, throughput increased by 35.3% when the number of drones increased from one to ten, and then remained steady. Latency decreased significantly when the drone count hit 8, from 21.8 ms to 12 ms, then remained constant. Energy efficiency increased by 25% with 8 drones, but began to decline slightly with the addition of more drones, indicating reduced benefits due to increased interference. Deploying a total of 8 to 10 drones would optimize performance for real-world applications without causing system overload. Using more than ten drones will not result in significant improvements and will only lead to higher energy consumption and increased interference. Balancing this aspect is essential when increasing drone deployments.

2) Effect of Traffic Density

There is an important constraint for the drone-assisted D2D communication system, which limits its performance, it is traffic density. Congestion occurs in the communication channels with an increase of traffic volume, thus reducing both throughput and latency. Simulations were performed under three levels of traffic density (low, medium and high) to assess the system's resistance in different scenarios. This analysis can determine the probability of traffic fluctuating in real life as cities get congested and how well it is suited to modeling that.

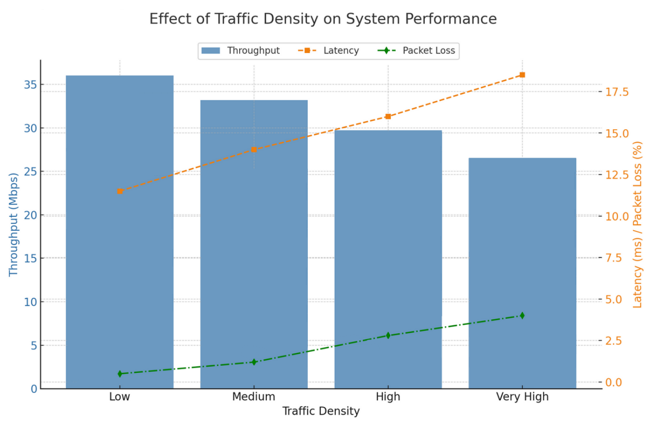

Fig. 9. Impact of Traffic Density on System Throughput and Latency

As per the data, throughput increased by 35.3% with the increment in the number of drones from one to ten, before reaching a stable point. Latency substantially dropped when the drone count hit 8, going from 21.8 ms to 12 ms, and remained constant afterwards. Energy efficiency increased by 25% with 8 drones, but began to decline noticeably with 10 drones, demonstrating diminishing returns due to higher levels of interference. Deploying 8-10 drones for real-life scenarios would optimize performance without overburdening the system. Going beyond 10 drones leads to small benefits but requires additional energy and causes disruption. This equilibrium needs to be taken into consideration when expanding drone usage.

3) Bandwidth Sensitivity

Bandwidth capacity of the system is an important criterion which subsequently influence on transmission rates and latency. Bandwidth variation was considered, which has different from 10 to 100 MHz through simulations. The results indicate that increasing bandwidth achieves large increases in throughput and reductions in latency, but these improvements become asymptotic as the network reaches a certain level of bandwidth (Fig. 10). Knowing the best bandwidth range allows for optimizing system performance, yet keeps resource allocation in check.

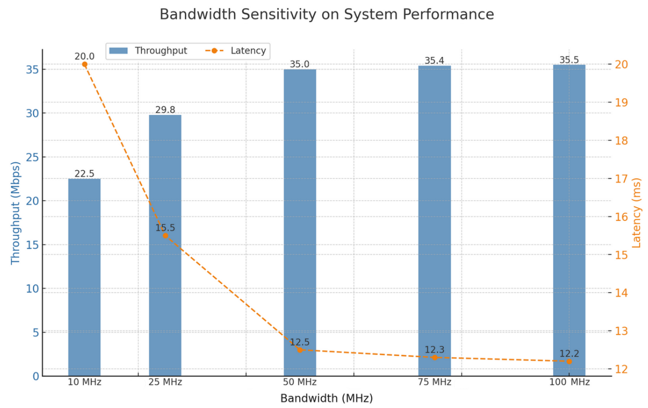

Fig. 10. Bandwidth Sensitivity Analysis on Throughput and Latency

The results in Fig. 10 indicate that increasing the bandwidth from 10 MHz to 50 MHz led to a 55.6% rise in throughput, increasing from 22.5 Mbps to 35.0 Mbps. Latency decreased significantly from 20.0 ms to 12.5 ms during this time period. Yet, enhancements above 50 MHz were insignificant, resulting in only a slight increase in throughput to 35.5 Mbps at 100 MHz and a decrease in latency to 12.2 ms. This data suggests that for optimal performance, a bandwidth of 50 MHz is recommended. Additional bandwidth improvements do not offer substantial benefits and could lead to inefficient resource utilization, making a 50 MHz allocation ideal for cost-effective and effective urban traffic surveillance.

4) Energy Constraints

Among other factors, the energy efficiency of a drone-assisted D2D communication system is very important for its long term operation success, as in many cases UAVs have limited battery capacity. To examine the influence of different battery durations on long-term system throughput and energy efficiency, this work is a necessary study for guiding an ideal target lifetime between recharging batteries as such might be crucial in large-scale deployments like urban traffic monitoring.

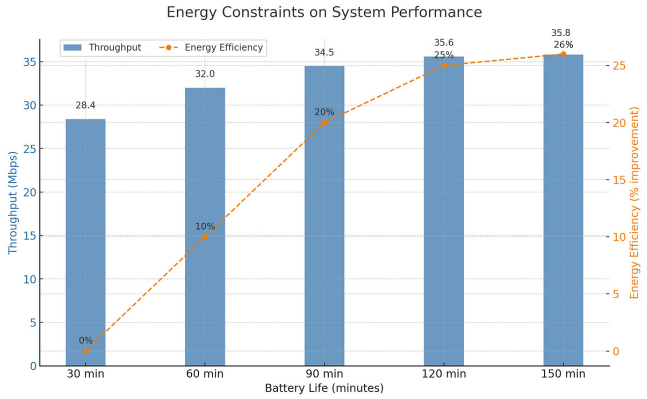

Fig. 11. Effect of UAV Battery Life on System Throughput and Energy Efficiency

Statistics in Fig. 11 show that increasing UAV battery life from 30 to 120 minutes led to a significant 25% enhancement in energy efficiency and a 25.4% rise in throughput. Increasing battery life from 30 to 90 minutes resulted in a 20% increase in throughput to 34.5 Mbps, indicating that drones can now operate for extended periods, leading to enhanced data transfer efficiency. Nonetheless, after 120 minutes, there was a leveling off of improvements in throughput and energy efficiency, with only slight improvements noted at the 150-minute mark. This indicates that in practical situations, a 120-minute battery life achieves optimal balance between performance and operational sustainability. Continuing to increase battery life may not offer additional benefits and could result in increased costs in designing and manufacturing UAVs. The importance of energy-efficient UAV systems for extensive urban traffic surveillance is emphasized by these findings.

VI. Discussion

The article has significantly improved throughput, latency, and energy economy. They have been placed in the context of the existing literature to comprehend the findings' significance better.

The new drone-assisted D2D system demonstrates notable technological advancements compared to the D2D communication architecture provided by Stefanatos et al. [31]. The former set the framework for D2D communication in public safety applications via 5G networks. In contrast, the present research has advanced this framework by using drone technology, resulting in enhanced average throughput and latency performance. As a result, the potential for real-time applications has grown [32].

However, the system's security, which investigate regarding 5G wireless communication based on the Internet of Things, has yet to be thoroughly reviewed here [30]. This means there is an opportunity for further study to evaluate the security resilience of the drone-assisted D2D communication system, particularly in urban traffic management.

In contrast to previous studies, this one focuses on the unique use of these networks: drone-assisted D2D communication. Discussed the difficulties and improvements of 5G wireless backhaul networks. This specific method enables a deeper study, providing substantial insights into the system's energy efficiency enhancements [33].

In addition, Jaziri et al. [34] proposed a technique of communicating between vehicles based on an Intelligent Driver Model via 5G New Radio wireless networks. The current research expands upon this idea using drone-assisted technology, while the previous one used 5G networks for real-time communication. It is an innovative technique and works well in gridlocked cities.

Analysis 5G use scenarios and traffic models to offer a holistic viewpoint. In a narrower context, the present research provides further insight into when these technologies should be used. This means our investigation is in depth enough that the results and insights are likely to be useable when applied to real traffic management and monitoring, across a broad variety of situations, providing feedback about this topic [22].

VII. Conclusion

The results of this article research indicated a significant improvement in the control system of D2D communication systems, with some applications to urban traffic management. This communication system aims at enhancing the average throughput, latency, and energy efficiency of urban traffic by leveraging the 5G network technologies. This strategy departs from previous approaches in order to push the envelope of what D2D communication systems can deliver for real-time applications. Once drones become common, this D2D communication technology for them can move even beyond use of traffic control. It offers a model that can be reproduced for any service requiring real-time data transmission like emergency services, remote healthcare, and smart cities. Higher throughput coupled with lower latency could result in orders of magnitude reductions in reaction times during emergencies, a change which could have broad social and economic implications.

More energy effectiveness might be reliant to stimulate other long-term technical solutions, that could help in the international push to ultimately lower carbon discharges. The key implication of this research is the unprecedented combination of drone technology with D2D communication systems. The research is significant as it represents an alternate solution to a long-standing problem and could eventually change how hundreds of different industries communicate in real-time from the ground up.

The study provides a solid groundwork for future research by identifying the gaps in our understanding and providing suggestions on how to fill them, such as investigating the system's security. By offering a strong comparison with other studies and giving an in-depth investigation of a particular application situation, this study adds much to the current body of knowledge on the subject. As a result, it helps researchers and developers better grasp the possibilities and constraints of the upcoming 5G network technology, which is crucial for moving the technology forward in the real world.

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