ISSN: 2519-9439

Rate-Splitting Coordination for Emergency Unmanned Aerial Vehicle Network Coverage Optimization

Hae-Won Seo[1]

[1] School of Electrical Engineering, Korea Advanced Institute of Science and Technology, Daejeon, Republic of Korea

Abstract

The rapid deployment of communication infrastructure is critical during natural disasters, where terrestrial networks are frequently compromised or entirely destroyed. Unmanned aerial vehicles have emerged as a highly flexible solution to provide on-demand emergency wireless coverage. However, managing co-channel interference and optimizing the trajectory of multiple unmanned aerial vehicles in a highly dynamic environment pose significant technical challenges. This paper investigates the application of rate-splitting multiple access as a coordination mechanism for emergency unmanned aerial vehicle networks. By splitting user messages into common and private parts, rate-splitting multiple access provides a generalized and robust interference management framework that bridges the gap between space-division multiple access and non-orthogonal multiple access. We formulate a joint optimization problem to maximize the minimum user rate, ensuring fairness and optimal coverage in disaster zones, by jointly optimizing the multi-unmanned aerial vehicle trajectories, power allocation, and rate-splitting parameters. Given the non-convex nature of the problem, we propose an alternating optimization algorithm based on successive convex approximation. Extensive simulations demonstrate that the proposed rate-splitting coordination approach significantly outperforms conventional orthogonal and non-orthogonal multiple access schemes in terms of coverage probability, energy efficiency, and overall network throughput. The results highlight the potential of rate-splitting to enhance the resilience and capacity of next-generation aerial emergency communication systems.

Keywords: Unmanned Aerial Vehicles, Rate-Splitting Multiple Access, Emergency Communications, Interference Management, Trajectory Optimization

1.Introduction

1.1 Motivation and Context in Emergency Communications

During large-scale natural disasters such as earthquakes, tsunamis, and hurricanes, traditional terrestrial telecommunications infrastructure is often severely damaged or incapacitated. The loss of cellular towers, fiber-optic backhauls, and power grids severely hampers the ability of first responders to coordinate rescue efforts and prevents affected civilians from reaching out for critical assistance. In these scenarios, the rapid establishment of a temporary communication network is of paramount importance to ensure the safety and survival of the affected population within the critical first seventy-two hours. Due to their high mobility, autonomous operation capabilities, and decreasing costs, unmanned aerial vehicles

ISSN: 2519-9439

have been increasingly utilized as aerial base stations to restore connectivity in disaster-stricken areas. Unmanned aerial vehicles can establish line-of-sight communication links more easily than ground-based systems, significantly mitigating signal attenuation and blockage caused by debris and uneven terrain. However, the deployment of multiple unmanned aerial vehicles to cover a wide disaster area introduces complex challenges related to spectrum scarcity, inter-cell interference, and energy constraints. Sentinel-2 offers optical land observations that can supply environmental context for coverage planning, subject to cloud cover, acquisition time and the resolution required by the application [1]. The dynamic topology of aerial networks requires sophisticated coordination mechanisms to ensure seamless coverage and equitable resource allocation among all ground users. Another relevant line of investigation concerns toward seamless sensing coverage for cellular Multi-Static integrated sensing and communication [2].

1.2 The Paradigm of Rate-Splitting Multiple Access

Traditional multiple access techniques, such as orthogonal multiple access, allocate distinct time or frequency resources to different users, which effectively eliminates inter-user interference but suffers from low spectral efficiency when dealing with a massive number of devices. To address the spectral efficiency limitations, non-orthogonal multiple access has been proposed, which allows multiple users to share the same time-frequency resources by leveraging the power domain and applying successive interference cancellation at the receiver. While non-orthogonal multiple access has shown promise, it is highly sensitive to channel state information inaccuracies and user channel disparities, making it less robust in the highly variable air-to-ground channels characteristic of unmanned aerial vehicle networks. Rate-splitting multiple access has recently emerged as a powerful and generalized interference management strategy for multi-antenna and multi-user networks. In rate-splitting multiple access, the message intended for a user is split into a common part and a private part. The common parts from multiple users are encoded together into a single common stream to be decoded by all users, while the private parts are encoded independently and decoded only by their respective intended receivers. By adjusting the power allocated to the common and private streams, rate-splitting multiple access can softly bridge the gap between treating interference as noise and decoding interference, providing superior robustness against imperfect channel state information and dynamic network topologies. Another relevant line of investigation concerns pareto-Optimal beamforming design for RSMA-RHS-Aided ISAC system with imperfect CSI [3].

1.3 Scope and Structure of the Study

The integration of rate-splitting multiple access into multi-unmanned aerial vehicle networks represents a paradigm shift for emergency communication optimization. In a multi-unmanned aerial vehicle scenario, rate-splitting can effectively mitigate both intra-cell and inter-cell interference, enabling denser deployments of aerial base stations without degrading the quality of service. This paper proposes a comprehensive framework for rate-splitting coordination in emergency unmanned aerial vehicle networks. We aim to maximize the minimum throughput among all ground users to guarantee fair and reliable communication, which is critical in emergency scenarios where every distress signal is of equal importance.

ISSN: 2519-9439

The problem entails the joint optimization of unmanned aerial vehicle trajectories, transmit power allocation across common and private streams, and rate allocation. The rest of this paper is structured as follows. Section 2 provides a detailed background and literature review of unmanned aerial vehicle communications and multiple access techniques. Section 3 presents the system architecture and formulates the mathematical models. Section 4 details the proposed rate-splitting coordination methodology and optimization algorithm. Section 5 presents the experimental setup, simulation results, and comprehensive performance analysis. Finally, Section 6 concludes the paper and outlines future research directions. Related work has addressed harmonic distortion optimization for Sigma-Delta modulators interface circuit of TMR sensors [4].

2. Background and Literature Review

2.1 Evolution of Aerial Base Stations in Disaster Scenarios

The concept of utilizing airborne platforms for communication dates back several decades, but the miniaturization of electronics and advancements in battery technology have recently made unmanned aerial vehicles a viable and cost-effective solution for civilian applications. In emergency scenarios, unmanned aerial vehicles operate primarily in three modes: as aerial relays connecting isolated ground clusters to a functional core network, as mobile data collectors gathering information from distributed internet of things sensors, and as standalone aerial base stations providing direct access to mobile users. The deployment of aerial base stations requires careful consideration of three-dimensional spatial positioning. Early research focused on finding the optimal static altitude and two-dimensional locations for single unmanned aerial vehicles to maximize the ground coverage area. Subsequent studies expanded this to multi-unmanned aerial vehicle scenarios, exploring circle-packing theories and genetic algorithms to optimize the overlapping coverage regions of multiple aerial nodes. However, static deployments fail to fully exploit the mobility of unmanned aerial vehicles. Dynamic trajectory planning allows unmanned aerial vehicles to fly closer to active ground users, adapting to the changing distribution of users as populations move away from hazard zones. This mobility, while advantageous, significantly complicates the management of inter-unmanned aerial vehicle interference, as the channel conditions and spatial separation between aerial nodes and users change continuously over time. Emergency coverage makes failures of accountability especially consequential. The governance perspective of Liao et al. [5] suggests that aerial rate-splitting decisions should preserve a reason for prioritizing one service group over another, even when the network is operating under degraded conditions. For a broader comparison, related research addresses design of interface circuits and lightweight PUF for TMR sensors [6].

2.2 Interference Management and Multiple Access Technologies

Interference management is the cornerstone of high-capacity wireless networks. In the context of aerial networks, line-of-sight channels are a double-edged sword: they provide strong desired signals but also cause severe co-channel interference from neighboring aerial base stations. Space-division multiple access utilizes multiple antennas to form directed beams, theoretically nulling interference at unintended receivers. However, spatial

ISSN: 2519-9439

multiplexing requires high-quality channel state information at the transmitter, which is exceptionally difficult to obtain in mobile unmanned aerial vehicle networks due to Doppler shifts and rapid topology changes. When channel state information is imperfect, space-division multiple access suffers from significant performance degradation due to residual interference. Non-orthogonal multiple access attempts to bypass this by scheduling users with disparate channel conditions on the same beam and relying on successive interference cancellation. Unfortunately, in unmanned aerial vehicle networks where ground users are closely clustered in evacuation zones, channel conditions may be highly similar, rendering non-orthogonal multiple access ineffective. Rate-splitting multiple access elegantly addresses these shortcomings by partially decoding interference. The common message in rate-splitting multiple access acts as an interference containment mechanism. By transmitting part of the interference as a decodable common message, users can subtract this major interference source before decoding their private messages, thereby maintaining high signal-to-interference-plus-noise ratios even when spatial channels are highly correlated or estimated inaccurately. Yao and colleagues examine interference management in ISAC–SAGINs based on Transformer-Enabled Mean-Field reinforcement learning method [7]. For a broader comparison, related research addresses design of magnetic sensor Array-Based PUFs for IoT security [8].

2.3 Optimization Techniques in Dynamic Networks

The mathematical optimization of unmanned aerial vehicle networks is inherently challenging due to the coupling of mechanical mobility constraints, communication variables, and nonlinear channel models. D* Lite provides an incremental graph-replanning method, relevant when changed requests or obstacles invalidate an existing plan [9]. Traditional approaches have heavily relied on block coordinate descent and alternating optimization to iteratively solve for trajectory and communication resources. Successive convex approximation is widely used to handle the non-convex terms related to signal-to-interference-plus-noise ratio and trajectory distances. In recent years, artificial intelligence and machine learning, particularly deep reinforcement learning, have gained traction for real-time unmanned aerial vehicle control. Deep reinforcement learning agents can learn optimal navigation policies through interaction with simulated environments, offering rapid decision-making capabilities once trained. However, reinforcement learning approaches often lack the mathematical performance guarantees required for mission-critical emergency services and struggle to generalize across diverse disaster topologies without extensive retraining. Therefore, deterministic optimization techniques remain crucial for establishing performance upper bounds and ensuring reliability. Developing algorithms that strike an optimal balance between computational complexity and optimality is a major focus of current research, particularly for battery-constrained aerial platforms. For a broader comparison, related research addresses jamming and eavesdropping defense scheme based on deep reinforcement learning in autonomous vehicle networks [10].

2.4 Unresolved Challenges and Research Gaps

Despite the extensive literature on unmanned aerial vehicle communications, the integration of rate-splitting multiple access into multi-unmanned aerial vehicle emergency networks

ISSN: 2519-9439

remains largely unexplored. Existing studies on rate-splitting multiple access primarily focus on static terrestrial base stations or single unmanned aerial vehicle scenarios with fixed trajectories. The dynamic interplay between the trajectory-dependent air-to-ground channels and the rate-splitting parameters introduces unique non-convexities that conventional optimization algorithms cannot handle efficiently. Furthermore, most studies assume perfect knowledge of the locations of ground users, which is unrealistic in a chaotic post-disaster environment. There is a pressing need for a comprehensive framework that jointly optimizes the flight paths of multiple unmanned aerial vehicles alongside the sophisticated transmit power and rate allocation required by rate-splitting multiple access, specifically under stringent energy and fairness constraints. This paper addresses these gaps by proposing an alternating optimization framework tailored for multi-unmanned aerial vehicle rate-splitting systems, ensuring equitable coverage for all distress signals in a targeted disaster area. MODIS vegetation indices provide regional vegetation context, which could support a canopy-related scene or coverage scenario but cannot replace local geometric or radio measurements [11]. Another relevant line of investigation concerns coordinated Rate-Splitting multiple access for emergency UAV-Enabled integrated sensing and communication [12].

3. System Architecture and Problem Formulation

3.1 Three-Dimensional Network Topology

We consider an emergency wireless communication system deployed over a disaster-stricken geographical area where the terrestrial cellular infrastructure has been rendered inoperable. The network comprises a set of multi-rotor unmanned aerial vehicles serving as mobile aerial base stations, and a set of stationary or slowly moving ground users representing individuals in need of rescue or communication. The continuous operational period is discretized into a finite number of time slots of equal duration. The duration of each time slot is chosen to be sufficiently small such that the locations of the unmanned aerial vehicles can be considered approximately constant within a single slot. The coordinate system is defined in a three-dimensional Cartesian space. The ground users are distributed across the horizontal plane, while the unmanned aerial vehicles operate at a fixed altitude to ensure safe clearance from terrain obstacles and to comply with aviation regulations. The trajectory of each unmanned aerial vehicle is defined by its horizontal coordinate sequence across all time slots. The mobility of the unmanned aerial vehicles is constrained by a maximum flying speed, preventing them from traveling beyond a certain distance between consecutive time slots. Furthermore, to avoid collisions in the airspace, a minimum safety distance is enforced between any pair of unmanned aerial vehicles at all times. Another relevant line of investigation concerns design of a novel Self-Test-on-Chip interface ASIC for capacitive accelerometers [13].

ISSN: 2519-9439

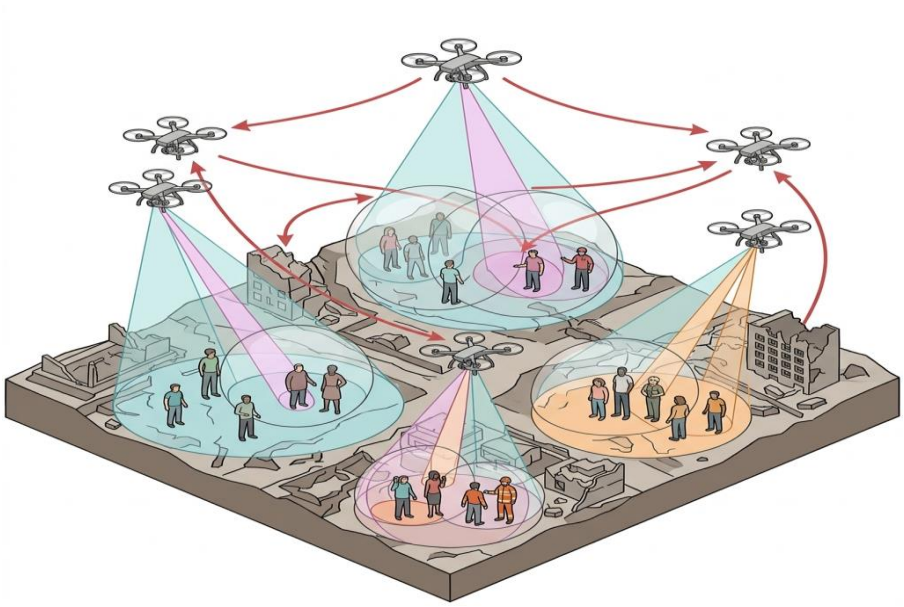


Figure 1Comprehensive Schematic of Rate

3.2 Air-to-Ground Channel Characteristics

The propagation environment between the aerial base stations and the ground users is characterized by the air-to-ground channel model. Unlike terrestrial channels, which are heavily dominated by Rayleigh fading due to multi-path propagation and lack of line-of-sight, air-to-ground channels typically exhibit a strong line-of-sight component. The probability of establishing a line-of-sight link depends heavily on the elevation angle between the user and the unmanned aerial vehicle, as well as the environmental parameters such as building density and height in the disaster zone. A higher elevation angle generally leads to a higher probability of line-of-sight propagation, as fewer obstacles obstruct the direct signal path. We adopt a probabilistic channel model that accounts for both line-of-sight and non-line-of-sight conditions. For analytical tractability in the optimization process, the large-scale channel power gain between a specific unmanned aerial vehicle and a ground user at a given time slot can be approximated based on the Euclidean distance. The mathematical representation of the large-scale channel power gain incorporates the channel gain at a reference distance and the path loss exponent, which dictates how rapidly the signal degrades over distance. Related work has addressed vision, framework, and future directions [14].

$$h = \frac{\beta_0}{d^{\alpha}}$$

In the formula above, the parameter represents the channel gain at a reference distance of one meter, while the distance term captures the three-dimensional separation between the transmitter and the receiver, and the path loss exponent governs the attenuation severity. Wang and colleagues examine reinforced Fuzzy-Rule-Based neural networks realized through streamlined feature selection strategy and fuzzy clustering with distance variation [15].

ISSN: 2519-9439

3.3 Rate-Splitting Multiple Access Encoding and Decoding

At the physical layer, each unmanned aerial vehicle employs the rate-splitting multiple access protocol to serve its associated ground users simultaneously in the same frequency band. Before transmission, the data intended for each user is split into a common message and a private message. The common messages for all users served by a particular unmanned aerial vehicle are combined and encoded into a single super-common stream. This super-common stream is designed to be decodable by all users within the cell using a public codebook. Conversely, the private messages are encoded independently into private streams intended strictly for their respective users. The unmanned aerial vehicle transmits a superposition of the super-common stream and all the private streams. At the receiver side, each ground user first attempts to decode the super-common stream by treating all private streams as unstructured noise. Once the common stream is successfully decoded, the user extracts its specific common message fraction. Subsequently, the user performs successive interference cancellation to subtract the reconstructed common signal from the received aggregated signal. After the removal of the common stream, the user decodes its own private stream, treating the private streams of other users as noise. The signal-to-interference-plus-noise ratio for decoding the common message must satisfy the requirements of the user with the weakest channel to ensure successful decoding by all. Wang and colleagues examine hyperbolic user identity linkage across social networks [16].

$$\gamma_c = \frac{P_c|h|^2}{\sum P_p|h|^2 + \sigma^2}$$

The formula expresses the signal-to-interference-plus-noise ratio for the common stream, highlighting the power allocated to the common stream in the numerator, and the interference from all private streams plus the background noise variance in the denominator. The total achievable data rate for a user is the sum of its allocated portion of the common stream rate and its independently decoded private stream rate. Related work has addressed OTFS-ISAC system with sub-nyquist ADC sampling rate [17].

4. Rate-Splitting Coordination Methodology

4.1 Max-Min Fairness Optimization Formulation

In the context of emergency communications, ensuring that all trapped or displaced individuals receive adequate connectivity is far more critical than maximizing the peak throughput of a few users who happen to be in favorable channel conditions. Consequently, we formulate the network optimization problem with the objective of maximizing the minimum average data rate among all ground users over the entire operational period. This max-min fairness objective function guarantees that the optimization process allocates sufficient resources to cell-edge users and those suffering from severe blockage. The decision variables in this joint optimization problem encompass the two-dimensional trajectory coordinates of all unmanned aerial vehicles at every time slot, the transmit power allocated to the common stream, the transmit power allocated to the individual private streams, and the continuous rate allocation variables that determine how the common stream rate is

ISSN: 2519-9439

distributed among the users. The optimization is subject to a multitude of physical and systemic constraints. These include the maximum velocity constraint, preventing the unmanned aerial vehicles from exceeding mechanical limits, the collision avoidance constraint ensuring safe inter-UAV distances, the total instantaneous power budget constraint at each aerial base station, and the non-negativity constraints on all power and rate variables. Yang and colleagues examine adaptive joint configuration optimization for collaborative inference in Edge-Cloud systems [18].

$$maxmin_k \sum_{t=1}^{T} R_k[t] quads.t. quad |q_t - q_{t-1}| \leq V_{max}$$

The block mathematical expression delineates the core objective: maximizing the minimum sum rate over the total flight time, subject strictly to the dynamic kinematic bound that the distance traveled between two discrete time intervals cannot surpass the maximum velocity threshold. The literature also considers cost-Aware layer-7 load balancing framework with deep traffic prediction for dynamic optimization of enterprise cloud services [19].

4.2 Alternating Optimization and Successive Convex Approximation

The formulated max-min optimization problem is highly non-convex. The non-convexity arises primarily from the complex interference terms in the denominator of the signal-to-interference-plus-noise ratio expressions, the coupling between power allocation variables and trajectory variables, and the non-convex nature of the lower bound collision avoidance constraint. Finding a global optimum for such a multivariate, non-linear programming problem is generally intractable within a reasonable timeframe. Therefore, we propose a computationally efficient methodology based on the principles of alternating optimization and successive convex approximation. The core idea of alternating optimization is to decouple the original intractable problem into two or more tractable subproblems. In our framework, we decompose the problem into two main blocks: the communication resource allocation block and the trajectory design block. In the first step, we fix the unmanned aerial vehicle trajectories and optimize the common and private power allocations along with the rate-splitting parameters. Although this subproblem is still non-convex due to the interference terms, it can be reformulated into a sequence of convex approximations using first-order Taylor expansions to linearly lower-bound the non-convex throughput functions. The literature also considers hybrid structure noise shaping SAR ADC [20].

4.3 Algorithmic Execution and Complexity Analysis

Once the communication resources are optimized for a given set of trajectories, the algorithm proceeds to the second block, where the power and rate variables are fixed, and the unmanned aerial vehicle trajectories are updated. The trajectory subproblem also contains non-convexities, specifically in the channel gain functions which depend inversely on the distance, and the inter-UAV distance constraints. We employ the introduction of slack variables and apply successive convex approximation to iteratively update the flight paths. The two blocks are executed alternately until the fractional increase in the objective function value falls below a predefined convergence threshold. The computational complexity of the proposed alternating optimization algorithm depends on the number of unmanned aerial vehicles, the number of users, the number of time slots, and the number of iterations required

ISSN: 2519-9439

for convergence. Because each subproblem is transformed into a standard convex optimization problem (such as a second-order cone program), it can be solved efficiently using interior-point methods provided by modern off-the-shelf solvers. Feng and colleagues examine number and phase modulation approach [21].

Code Listing 1: Pseudo-code for Iterative Rate-Splitting Trajectory Algorithm

```
def optimize_emergency_uav_network(users, uavs, time_slots, max_iter):
    # Initialize trajectories and power allocations
    trajectories = generate_initial_circular_paths(uavs, time_slots)
    power_alloc = initialize_equal_power(uavs, users)
    iteration = 0
    convergence_error = float('inf')
    min_rate_history = []

    while iteration < max_iter and convergence_error > 1e-4:
        # Step 1: Optimize Communication Resources (RSMA)
        new_power, new_rates = solve_rsma_allocation(trajectories, users)

        # Step 2: Optimize UAV Trajectories using SCA
        new_trajectories = solve_trajectory_sca(new_power, new_rates, users)

        # Calculate objective (max-min rate)
        current_min_rate = calculate_system_min_rate(new_trajectories, new_power)

        # Check convergence
        if iteration > 0:
            convergence_error = abs(current_min_rate - min_rate_history[-1])

        # Update variables
        trajectories = new_trajectories
        power_alloc = new_power
        min_rate_history.append(current_min_rate)
        iteration += 1

    return trajectories, power_alloc, min_rate_history
```

ISSN: 2519-9439

The pseudo-code illustrates the high-level control flow of the coordination algorithm. The iterative loop guarantees monotonic convergence, as the objective function value cannot decrease at any step of the alternating optimization process, and the upper bound is strictly limited by the finite transmit power and channel capacities. Liao et al. connect explainability with resilience [5]. For the coordination algorithm, a useful implementation test is whether an operator can reconstruct why a common-stream allocation changed after a UAV outage using only the retained decision record.

5. Experimental Results and Analysis

5.1 Simulation Environment Configuration

To rigorously evaluate the performance of the proposed rate-splitting coordination mechanism for emergency unmanned aerial vehicle networks, we constructed a comprehensive simulation environment modeling a standard post-disaster urban scenario. The simulation area is defined as a two-kilometer by two-kilometer square region. We assume that a catastrophic event has disabled all ground base stations within this perimeter. One hundred ground users are distributed across the area, exhibiting clustered formations that mimic realistic disaster congregation points, such as temporary medical tents or evacuation shelters. We deploy three unmanned aerial vehicles to provide continuous coverage over a simulated flight duration of two hundred seconds. The channel parameters are configured to reflect a typical suburban environment with moderate line-of-sight blockages. To provide a thorough comparative analysis, we benchmark our proposed rate-splitting multiple access scheme against two baseline communication protocols widely discussed in the literature: space-division multiple access and power-domain non-orthogonal multiple access. The baseline schemes are subjected to the identical trajectory and power optimization frameworks, substituting only the physical layer multiple access equations. Related work has addressed joint-Aware video processing with Edge-Cloud collaboration for DNN inference [22].

Table 1Simulation Parameters Configuration

Parameter Description	Symbol	Assigned Value
Operational Area Dimensions	L x W	2000 m x 2000 m
Number of UAVs / Users	M / K	3 / 100
Flight Altitude	H	100 m
Maximum UAV Velocity	V_max	20 m/s
Carrier Frequency	f_c	2.4 GHz
System Bandwidth	B	10 MHz
Background Noise Power	\sigma^2	-110 dBm

ISSN: 2519-9439

Maximum Transmit Power per UAV	P_max	5 Watts

5.2 Coverage Optimization and Throughput Performance

The experimental results demonstrate a decisive advantage of the rate-splitting multiple access framework in maintaining robust communication links. The primary performance metric analyzed is the max-min user throughput, which directly translates to the quality of emergency coverage. Initially, as the unmanned aerial vehicles fly from their launch positions toward the user clusters, the throughput is low for all schemes. However, as the unmanned aerial vehicles approach the optimal overhead positions, the rate-splitting system achieves significantly higher minimum throughput compared to the baselines. Space-division multiple access struggles heavily with inter-user interference because the clustering of users results in highly correlated channel vectors, making it nearly impossible to form distinct spatial beams without severe leakage. Non-orthogonal multiple access performs marginally better than space-division multiple access by leveraging the power domain, but its performance degrades when user channel gains are too similar, causing the successive interference cancellation process to fail or propagate errors. Rate-splitting multiple access seamlessly manages this by adjusting the power of the common stream to absorb the unresolvable interference. The dynamic adjustment of the rate-splitting parameters allows the unmanned aerial vehicles to maintain a high minimum rate even when users are densely packed. The literature also considers emergent symbolic languages in multi-agent reasoning [23].

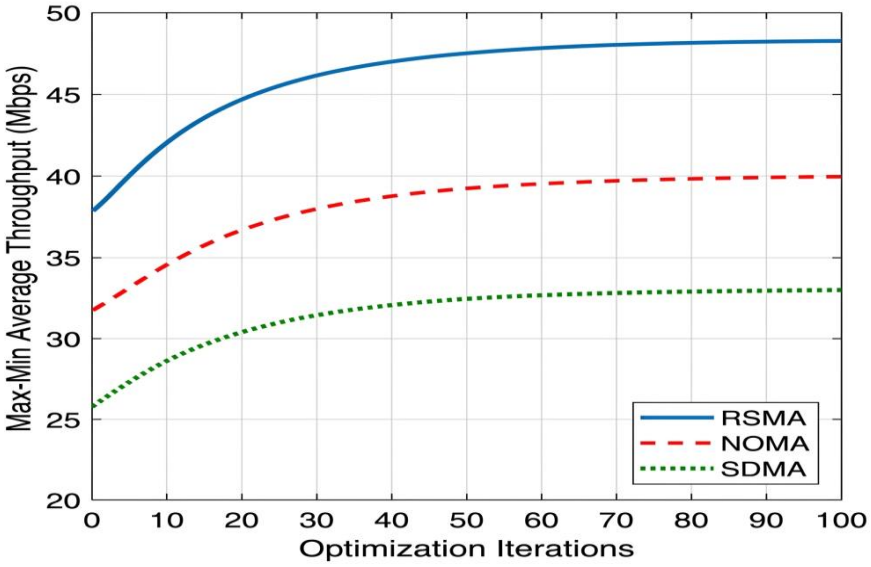


Figure 2Convergence and Throughput Analysis Chart

Table 2Comparative Analysis of Coverage Probability

Multiple Access Scheme	Minimum Rate Target 1 Mbps	Minimum Rate Target 2 Mbps	Minimum Rate Target 5 Mbps

ISSN: 2519-9439

Orthogonal Multiple Access	85.2%	61.4%	12.5%
Space-Division Multiple Access	88.5%	70.2%	18.3%
Non-Orthogonal Multiple Access	92.1%	76.8%	25.1%
Rate-Splitting Multiple Access	98.7%	89.5%	41.2%

5.3 Energy Efficiency Analysis

In an emergency context, the operational lifespan of the aerial network is strictly bound by the onboard battery capacity of the unmanned aerial vehicles. Therefore, energy efficiency is a critical secondary metric. Energy efficiency in this context is defined as the ratio of the total sum throughput of the network to the total energy consumed. The total energy consumption includes both the communication transmit power and the mechanical propulsion energy required to keep the multi-rotor unmanned aerial vehicle aloft and moving. Another relevant line of investigation concerns adaptive guidance semantically enhanced via multimodal LLM for Edge-Cloud object detection [24].

$$eta = \frac{\sum_{k=1}^{K} R_k}{P_{comm} + P_{prop}}$$

The formula calculates the system energy efficiency by dividing the aggregated sum rate of all users by the sum of communication transmission power and aerodynamic propulsion power. Because propulsion power generally dominates the energy budget, optimizing the trajectory to find the shortest paths that still satisfy communication requirements is vital. Our results show that the rate-splitting scheme achieves higher energy efficiency than the non-orthogonal baseline. Because rate-splitting manages interference more effectively, the unmanned aerial vehicles do not need to fly as close to the individual users to overcome interference with raw signal power. This allows the unmanned aerial vehicles to take shorter, more central flight paths, significantly reducing propulsion energy consumption while simultaneously achieving higher data rates. For a broader comparison, related research addresses augmenting cybersecurity in smart urban energy systems through IoT and blockchain technology within the digital twin framework [25].

5.4 Practical Implications for Emergency Response

The robust performance of the rate-splitting coordination algorithm has profound implications for practical disaster management protocols. Emergency response agencies require systems that are not only high-performing under ideal conditions but resilient to uncertainty. In a real disaster, user locations are not perfectly static, and channel state information is frequently outdated due to processing delays. The ability of the common message in rate-splitting to act as a buffer against channel estimation errors means that

ISSN: 2519-9439

rescue teams can rely on the unmanned aerial vehicle network to deliver critical data—such as high-resolution medical images, real-time video feeds from search and rescue drones, and vital sign telemetry—without devastating packet loss. Furthermore, the max-min fairness design ensures that isolated survivors located at the edges of the disaster zone, who might be ignored by a throughput-maximizing cellular algorithm, are guaranteed a minimum connectivity threshold sufficient for text messaging and voice calls. Another relevant line of investigation concerns switching strategy for connected vehicles under variant harsh weather conditions [26].

6. Conclusion

6.1 Summary of Methodological Findings

This paper has comprehensively investigated the application of rate-splitting multiple access to optimize emergency coverage in multi-unmanned aerial vehicle networks. The unpredictable and severe nature of natural disasters necessitates the rapid deployment of resilient aerial infrastructure to replace disabled terrestrial base stations. Through our rigorous mathematical modeling, we demonstrated that traditional space-division and power-domain non-orthogonal access schemes exhibit fundamental limitations when dealing with the high-interference, dynamic topologies inherent to multi-drone deployments. By partitioning user data into common and private streams, the proposed rate-splitting framework provides a superior mechanism for managing inter-cell and intra-cell interference dynamically. We formulated a complex joint optimization problem focusing on max-min fairness to guarantee reliable communication for all ground users, regardless of their location within the disaster zone. The developed alternating optimization algorithm, utilizing successive convex approximation, successfully navigated the non-convexities of the system, optimizing unmanned aerial vehicle flight paths, transmission power, and stream rate allocation concurrently. The extensive simulation results confirmed that the rate-splitting approach dramatically improves both the minimum guaranteed throughput and the system's overall energy efficiency, proving its viability as a cornerstone technology for post-disaster communication restoration. For a broader comparison, related research addresses optimizing HIV interventions for multiplex social networks via Partition-Based random search [27].

6.2 Future Research Directions

While the findings presented in this study offer a significant leap forward for aerial emergency communications, several critical avenues for future research remain open. First, the integration of massive multiple-input multiple-output antenna arrays onto unmanned aerial vehicles is becoming increasingly feasible as hardware weight decreases. Combining rate-splitting algorithms with three-dimensional massive multi-antenna beamforming could further exponentialize spectral efficiency. Second, the deployment of intelligent reflecting surfaces on high-altitude platforms or intact building facades could assist the unmanned aerial vehicles by proactively shaping the radio propagation environment, creating an even more favorable line-of-sight environment. Object-fidelity diffusion for remote-sensing imagery [28] could support synthetic environmental scenarios, but coverage or routing evaluation must verify that generated objects preserve the geometry relevant to a radio link.

ISSN: 2519-9439

Third, transitioning from deterministic convex optimization to decentralized, multi-agent federated learning models could drastically reduce the computational burden on the aerial nodes, allowing them to coordinate their trajectories and power allocations autonomously in real-time without relying on a centralized controller. Expanding the rate-splitting framework to encompass these heterogeneous and intelligent network architectures will be essential for realizing the next generation of instantaneous, high-capacity emergency response networks. Related work has addressed cooperative backscatter communications with reconfigurable intelligent surfaces: an APSK approach [29].

References

[1] Drusch, M., Del Bello, U., Carlier, S., Colin, O., Fernandez, V., Gascon, F., et al. (2012). Sentinel-2: ESA's optical high-resolution mission for GMES operational services. Remote Sensing of Environment, 120, 25–36.

[2] Li, R., Xiao, Z., & Zeng, Y. (2023). Toward seamless sensing coverage for cellular multi-static integrated sensing and communication. IEEE Transactions on Wireless Communications, 23(6), 5363-5376.

[3] Xiao, W., Tan, Q., Chen, M., Yao, Y., & Shu, F. (2026). Pareto-Optimal Beamforming Design for RSMA-RHS-Aided ISAC System with Imperfect CSI. IEEE Transactions on Vehicular Technology.

[4] Li, X., Hu, J., & Liu, X. (2020). Harmonic Distortion Optimization for Sigma-Delta Modulators Interface Circuit of TMR Sensors.Sensors,20(4), 1041.

[5] Liao, Q., Chen, Y., He, S., Wang, R., Xu, W., & Chu, W. (2025). Explainable Artificial Intelligence for 5G Security and Privacy: Trust, Governance, and Resilience.

[6] Li, X., Wang, P., Li, G., Ni, L., & Zhang, Y. (2023). Design of interface circuits and lightweight PUF for TMR sensors. IEEE Sensors Journal, 23(11), 11754-11761.

[7] Yao, Y., Lu, Z., Chen, G., Huang, C., Feng, C., & Quek, T. Q. (2026). Interference Management in ISAC-SAGINs Based on Transformer-Enabled Mean-Field Reinforcement Learning Method. IEEE Transactions on Wireless Communications.

[8] Wang, S., Zhang, X., Wang, P., & Li, X. (2026). Design of Magnetic Sensor Array-Based PUFs for IoT Security. IEEE Transactions on Instrumentation and Measurement, 75, 1-9.

[9] Koenig, S., & Likhachev, M. (2002). D* Lite. In Proceedings of AAAI.

[10] Yao, Y., Zhao, J., Li, Z., Cheng, X., & Wu, L. (2023). Jamming and eavesdropping defense scheme based on deep reinforcement learning in autonomous vehicle networks. IEEE Transactions on Information Forensics and Security, 18, 1211-1224.

[11] Huete, A., Didan, K., Miura, T., Rodriguez, E. P., Gao, X., & Ferreira, L. G. (2002). Overview of the radiometric and biophysical performance of the MODIS vegetation indices. Remote Sensing of Environment, 83(1–2), 195–213.

[12] Wei, X., Li, R., Chen, Y., Xu, L., Wang, L., & Han, Z. (2026). Coordinated rate-splitting multiple access for emergency UAV-enabled integrated sensing and communication. IEEE Transactions on Cognitive Communications and Networking.

[13] Li, X., Wang, P., Li, G., & Zhang, Y. (2023). Design of a novel self-test-on-chip interface ASIC for capacitive accelerometers. IEEE Transactions on Circuits and Systems I: Regular Papers, 70(7), 2834-2843.

[14] Li, Q., Ye, Q., Zhang, N., Zhang, W., & Hu, F. (2025). Digital-twin-enabled industrial IoT: Vision, framework, and future directions. IEEE Wireless Communications, 32(6), 173-181.

ISSN: 2519-9439

[15] Wang, Z., Kim, E. H., Oh, S. K., Pedrycz, W., Fu, Z., & Yoon, J. H. (2024). Reinforced fuzzy-rule-based neural networks realized through streamlined feature selection strategy and fuzzy clustering with distance variation. IEEE Transactions on Fuzzy Systems, 32(10), 5674-5686.

[16] Wang, F., Sun, L., & Zhang, Z. (2020, December). Hyperbolic user identity linkage across social networks. In GLOBECOM 2020-2020 IEEE Global Communications Conference (pp. 1-6). IEEE.

[17] Pu, H., Wang, X., Kumar, A., Su, L., & Li, H. (2025). OTFS-ISAC system with sub-nyquist ADC sampling rate. IEEE Journal on Selected Areas in Communications.

[18] Yang, Z., Ji, W., & Wang, Z. (2024). Adaptive joint configuration optimization for collaborative inference in edge-cloud systems. Science China Information Sciences, 67(4), 149103.

[19] Wu, C., Xu, C., & Liu, Y. (2026). L7-COLO: A Cost-Aware Layer-7 Load Balancing Framework with Deep Traffic Prediction for Dynamic Optimization of Enterprise Cloud Services. Fundamental Scientific Reports in Multidisciplinary Areas, 2(02), 235-249.

[20] Ren, S., Li, X., Shao, Z., Gong, M., & Ren, M. (2025). A Hybrid Structure Noise Shaping SAR ADC.Journal of Circuits, Systems and Computers,34(05), 2550135.

[21] Feng, Y., Li, Q., Chen, Y., Wu, Q., & Wen, M. (2024). RIS-aided symbiotic radio: A number and phase modulation approach. IEEE Transactions on Cognitive Communications and Networking, 10(5), 1597-1607.

[22] Yang, Z., Ji, W., Guo, Q., & Wang, Z. (2023, October). Javp: Joint-aware video processing with edge-cloud collaboration for dnn inference. In Proceedings of the 31st ACM International Conference on Multimedia (pp. 9152-9160).

[23] Pei, Z., Huang, Q., & Wang, S. (2026). When LLMs develop languages: Symbolic communication for efficient multi-agent reasoning. arXiv preprint arXiv:2606.29354.

[24] Hu, Y., Yang, Z., Zhao, C., & Ji, W. (2026, May). Adaptive guidance semantically enhanced via multimodal llm for edge-cloud object detection. In ICASSP 2026-2026 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP) (pp. 12962-12966). IEEE.

[25] Meng, X., & Zhu, L. (2024). Augmenting cybersecurity in smart urban energy systems through IoT and blockchain technology within the Digital Twin framework. Sustainable Cities and Society, 106, 105336.

[26] Liu, J., Nazeri, A., Zhao, C., Abuhdima, E., Comert, G., Huang, C. T., & Pisu, P. (2023). Switching strategy for connected vehicles under variant harsh weather conditions. IEEE Journal of Radio Frequency Identification, 7, 371-378.

[27] Zhang, Q., Zhong, L., Gao, S., & Li, X. (2018). Optimizing HIV interventions for multiplex social networks via partition-based random search. IEEE transactions on cybernetics, 48(12), 3411.

[28] Ye, Z., Ma, S., Yang, J., Yang, X., Yang, Y., Gong, Z., ... & Wang, H. (2026, April). Object fidelity diffusion for remote sensing image generation. In International Conference on Learning Representations (Vol. 2026, pp. 3258-3278).

[29] Li, Q., Feng, Y., Wen, M., Wen, J., Alexandropoulos, G. C., Basar, E., & Poor, H. V. (2024). Cooperative backscatter communications with reconfigurable intelligent surfaces: An APSK approach. IEEE Transactions on Wireless Communications, 23(11), 16218-16233.