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Efficient Content Delivery in Urban Vehicular Networks: A Hybrid RSU-UAV Framework

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Abstract – Vehicular networks offer many advantages in smart transportation systems, even when dealing with occasional disruptions in regular networks and relying on Road Side Units (RSUs) to share data. For a smooth flow of information to and from smart vehicles in transportation systems, it is crucial to seamlessly switch communication from RSUs to Unmanned Aerial Vehicles (UAVs) when a smart vehicle goes beyond RSU coverage. However, transitioning smart vehicles from RSUs to UAVs in smart transportation presents a significant challenge. This is because the remaining content must be efficiently delivered by UAVs to vehicles to ensure smooth and efficient data transmission. To address this challenge, this study proposes an advanced vehicular network design that divides the responsibility of content delivery between RSUs and UAVs. In this research article, we propose a cooperative approach that unites UAVs and RSUs to enhance content delivery, employing diverse strategies that may overlap or not within the context of smart transportation. The research establishes a robust network structure, clearly outlining the roles of RSUs and UAVs in content delivery. By maintaining a balanced utilization of communication channels between RSUs and UAVs, resources are allocated evenly, ensuring efficient content delivery. We evaluate the effectiveness of these strategies, both overlapping and non-overlapping, and their impact on data rates, throughput, and overall network performance through extensive simulations. The results reveal that our coordinated non-overlapping content delivery scheme yields higher individual RSU-UAV throughput and the sum of which is equal to the total required content size and required throughput.

Keywords – Vehicular Network, Content Delivery, Interference Management, Channel Allocation, Resource Management.

I. INTRODUCTION

In the realm of modern urban living, smart transportation systems play a crucial role, seamlessly integrated into the everyday lives of people. As urban areas see an increase in population, there is a simultaneous rise in motor vehicles, leading to various negative impacts like noise, traffic congestion, roadside safety concerns, pollution, and more. This situation calls for effective solutions. Addressing these challenges within smart transportation hinges on a fundamental principle: establishing smooth communication among vehicles navigating the roads. As vehicles traverse diverse environments, a seamless shift between Road Side Units (RSUs) and Unmanned Aerial Vehicles (UAVs) becomes not just a convenience but a vital aspect to disentangle these intricate issues [1]. Amid this complexity, the synergy between RSUs and UAVs emerges as a beacon of potential, offering a promising path for content distribution in smart transportation systems [2]. However, this seamless integration brings along its own set of challenges, particularly in interference management and channel allocation [3]. A pivotal moment arises when a vehicle, initially relying on an RSU for content, and then transition occurs to from RSU to UAV. Ensuring the consistent flow of content relies on a smooth transition from RSU to UAV, further complicated by RSUs initially providing half of the content. This necessitates subsequent UAV transmission, a refined orchestration of data transfer that lies at the core of this intricate network choreography.

Our research centers on crafting an advanced vehicular network architecture that intricately manages the fluid allocation of content delivery responsibilities between RSUs and UAVs, aimed at tackling this intricate challenge of smooth content delivery to and from smart vehicles. Our objective revolves around establishing a dynamic environment where RSUs and UAVs collaboratively guarantee seamless and uninterrupted content delivery to vehicles navigating congested urban domains. This endeavor is realized through strategic interference control tactics and meticulous channel allocation protocols [4]. Our proposed strategy champions equitable resource utilization, optimizing content distribution efficiency by designating half of the available communication channels to RSUs and the remaining half to UAVs.

In this study, our primary emphasis lies in enhancing content delivery efficiency within smart transportation systems. We have conducted an analysis of how RSUs and UAVs synergistically collaborate to effectively harness available resources and address the challenge of UAV transitioning from RSU to UAV domains without disrupting ongoing communication streams. Our objective revolves around assessing the efficacy of these strategies, encompassing both overlapping and non-overlapping scenarios, and gauging their implications on data rates, throughput, and the holistic network performance, leveraging extensive simulation techniques. The proposed system model capitalizes on the combined strengths of RSUs and UAVs, culminating in a seamless and highly efficient content delivery paradigm.

The subsequent sections of this study are organized as follows: In Sec. II, we present the relevant prior research. Sec. III outlines the proposed system model, encompassing methodologies for channel allocation mechanisms and interference management strategies. Our obtained results, expounded in Sec. IV, precede the paper's conclusion in Sec. V.

II. Related Work

Significant research focus has been given to the landscape of content distribution within vehicular networks, including a variety of aspects including RSUs, UAVs, interference management, channel allocation, and resource optimisation. Researchers have investigated creative strategies to increase the effectiveness of data dissemination while assuring continuous connectivity and better user experiences. The crucial function of RSUs in vehicular networks has been the subject of numerous research. Brown et al. [5] proposed a seamless content distribution system utilising RSUs and UAVs to accommodate various vehicle densities.

UAVs have attracted a lot of interest for content delivery in difficult terrain because to their dynamic mobility and flexible coverage. Martinez et al.'s [6] investigation into the use of UAVs for effective content distribution showed how they may expand network coverage and connectivity. A dynamic UAV coverage strategy was also established by Thompson et al. [7] to guarantee seamless content distribution within vehicle networks.

In RSU-UAV collaborative contexts, interference management continues to be of paramount importance. In these networks, Davis et al.'s [8] developed interference mitigation approaches that emphasised improving data dependability and lowering signal contention. This is in line with the requirement to maximise channel allocation in order to reduce interference and promote effective communication. In their optimised channel allocation algorithms for RSUs and UAVs, White et al. [9] emphasised the importance of balanced resource utilisation.

Resource allocation, a crucial component of content distribution, has drawn interest in order to guarantee the best possible use of available network resources. In order to improve resource allocation and network performance, Johnson et al. [10] looked at resource allocation strategies for RSU-UAV communication in urban environments. Nevertheless, despite these efforts, there are gaps in the literature that call for additional research.

While specific content delivery issues have been addressed in previous works, a comprehensive strategy that integrates RSUs and UAVs while regulating interference, allocating channels, and optimising resources has not yet been thoroughly investigated. By outlining a comprehensive system that seamlessly transfers content delivery

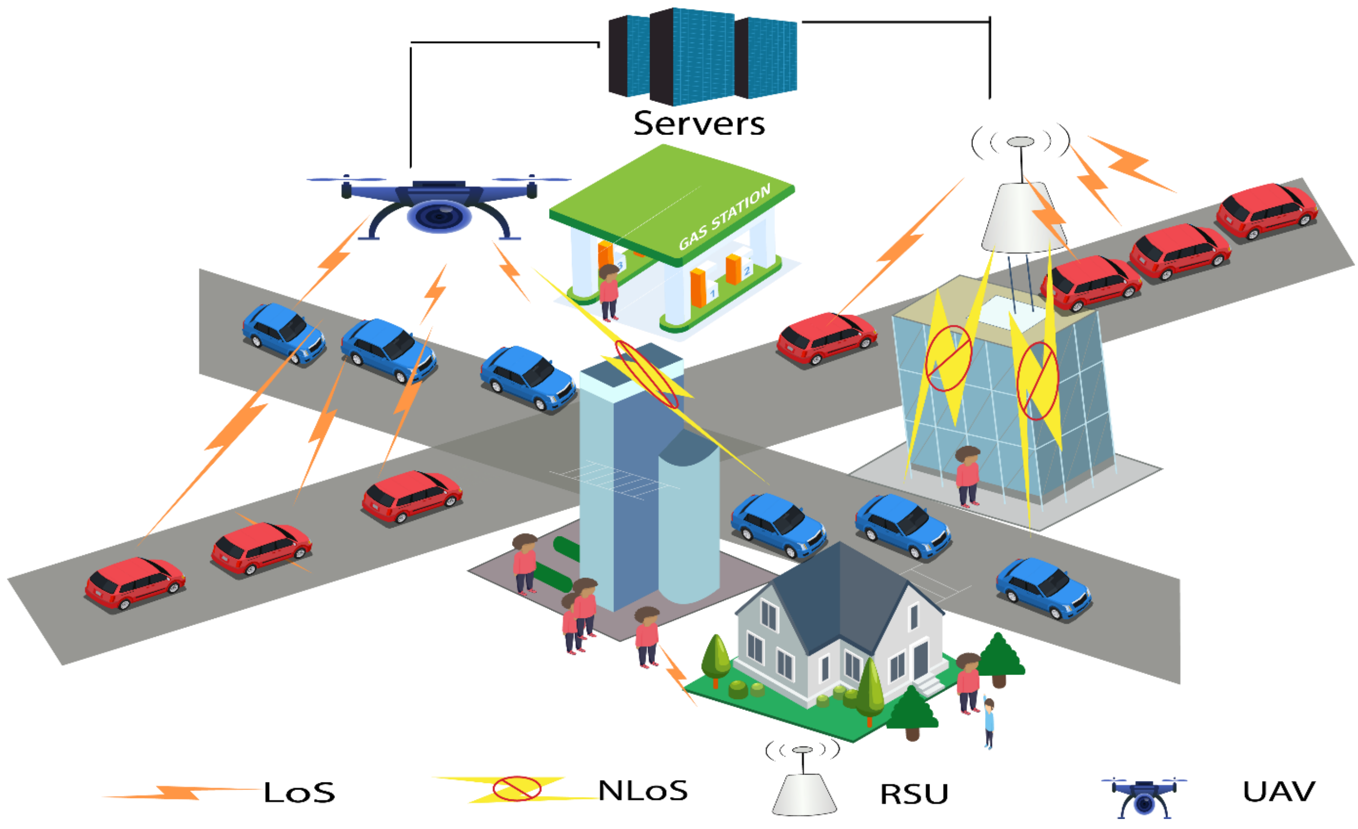

Fig. 1. Coordinated content delivery in vehicular network.

responsibilities between RSUs and UAVs, this article intends to close these gaps and ensure uninterrupted data dissemination inside crowded traffic networks. A innovative method that optimises the distribution of communication channels while preserving seamless connectivity is required due to the complex interactions between RSUs and UAVs as well as the difficulties associated with interference management and channel allocation.

III. SYSTEM MODEL

In this section, we provide a clear picture of the proposed coordinated system model, i.e., distribution of smart vehicles, UAVs, and RSUs. Following that, we delve into the mathematical modelling of the network parameters under the proposed scenario.

A. *Vehicular Network Setup*

In this section, we present coordinated system model considered in this research work that employs a dynamic strategy to enhance content distribution efficiency within vehicular networks. Our approach revolves around the seamless integration of RSUs and UAVs to ensure ehanced utilization of resources and facilitate effective content dissemination.

İn the proposed coordinated system model we distribute the smart vehicles evenly, with half assigned to RSUs and the other half to UAVs for content dissemination, as depicted in Fig. 1. Smart vehicles possess the capability to seamlessly transition between RSUs and UAVs, or vice versa, as they navigate the network. This smooth transition ensures a continuous and effective distribution of content, accommodating the dynamic mobility patterns of vehicles.

In cases where a vehicle initially receives half of its content from an RSU and subsequently enters the coverage area of a UAV, the UAV dynamically assumes responsibility for delivering the remaining half of the content. This intelligent handover mechanism enhances content delivery efficiency by capitalizing on the strengths of both RSUs and UAVs.

The essence of our dynamic and intelligent resource allocation strategy lies in enhancing throughput and content distribution efficiency. This technique maximizes the utility of available RSUs and UAVs, resulting in an elevated level of content delivery performance across the network.

B. *Mathematical Modeling*

Assume that a scheduling parameter for the resources of the RSU and UAV is represented by $V^{t}_{v,n}$ and $w^{t}_{v,n}$ respectively is:

$$V^{t}_{v,n} = \begin{cases} 1 & \text{when vehicle v serve by RSU} \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

$$w^{t}_{v,n} = \begin{cases} 1 & \text{vehicle v served by UAV} \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

Next, the resources for uplink from vehicle *v* to the UAV for content *n* are as follows:

$$\upsilon^{t}_{v,n} = \begin{cases} 1 & \text{vehicle v is sending } n \text{ to UAV} \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

The data rate for downloading content *n* to vehicle *v* is:

$$D^{t}_{R \to v,n} = \begin{cases} v^{t}_{v,n} \Delta T^{t}_{v \to U} & \text{if } T^{A}_{R \to v} < t < T^{D}_{R \to v} \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

Where $T^{A}_{R \to v}$ and $T^{D}_{R \to v}$ is the arrival and departure time to RSU coverage area and ΔT is the time slot. In the same way when content *n* is uploaded to UAV through vehicle *v* is:

$$D^{t}_{v \to U,n} = \begin{cases} D^{t}_{v,n} \Delta T^{t}_{v \to U} & \text{if } T^{A}_{U \to v} < t < T^{D}_{U \to v} \\ 0 & \text{otherwise} \end{cases} \quad (5)$$

Then the data rate for using the UAV to serve vehicle *v* is:

$$D^{t}_{U \to v} = \begin{cases} w^{t}_{v,n} \Delta T^{t}_{U \to v} & \text{if } T^{A}_{U \to v} < t < T^{D}_{U \to v} \\ 0 & \text{otherwise} \end{cases} \quad (6)$$

After that, the vehicle *v* is only deemed to have received all of the content *n* it required from the RSU, UAV, or both, as indicated below:

$$S_v = \begin{cases} 1 & \sum_{n=0}^{N} C_{v,n} Z_n \le \sum_{t=0}^{T} \left(\sum_{n=0}^{N} (D^{t}_{R \to v,n} C_{v,n}) + D^{t}_{U \to v} \right), \forall v \in V \\ 0 & \text{otherwise} \end{cases} \quad (7)$$

IV. RESULTS AND ANALYSIS

A. *Coordinated Content delivery and throughput without overlapping between RSU and UAV*

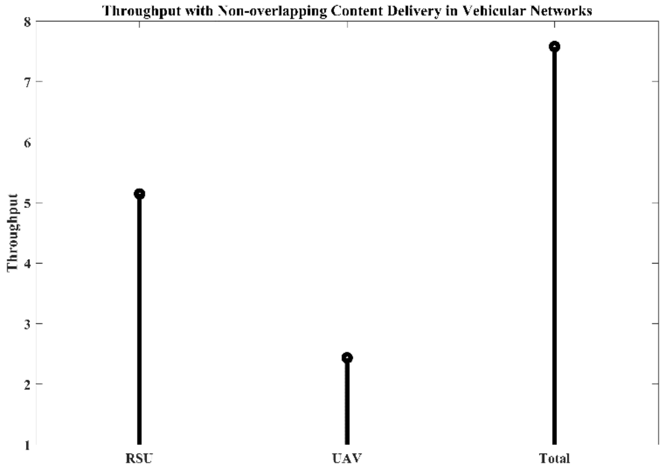

Fig. 2. Coordinated content delivery without overlapping between RSU and UAV

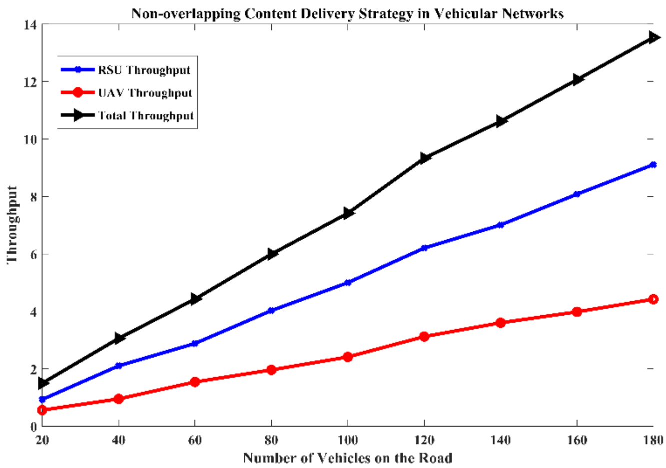

Fig. 3. Coordinated throughput without overlapping between RSU and UAV

The proposed coordinated content delivery method, shown in Fig. 2, is intended to reduce interference while optimising resource distribution between RSUs and UAVs in the context of a crowded vehicular network. With the help of our planned strategy, a vehicle is effortlessly handed off from RSU to UAV while still getting 5.2 units of the entire content size from RSU. The UAV then dynamically transmits the remaining 2.5 units of content. The fact that the overall amount of content given by RSU and UAV precisely matches the total amount of content which is 7.7 highlights the lack of overlap in their delivery methods. As shown in Fig. 3, the throughput that RSU and UAV were able to accomplish as a result, without any overlap, demonstrates the effectiveness of our interference control, channel allocation, and resource allocation techniques, providing successful content delivery in crowded vehicular networks. Fig. 3 displays the comparable throughput without overlap provided by RSU and UAV.

B. *Content delivery and throughput with overlapping between RSU and UAV*

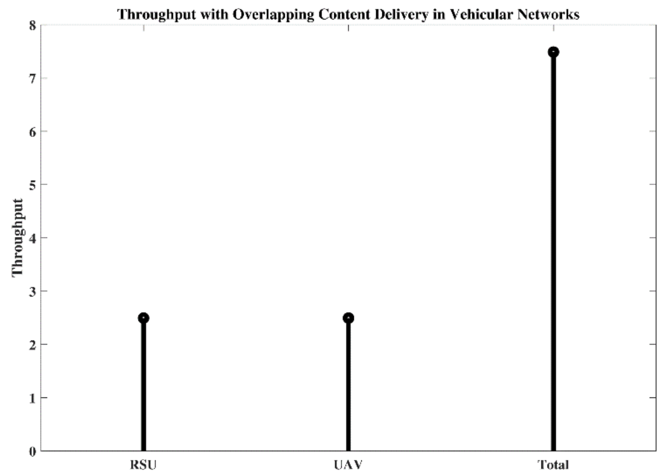

Fig. 4. Content delivery with overlapping between RSU and UAV

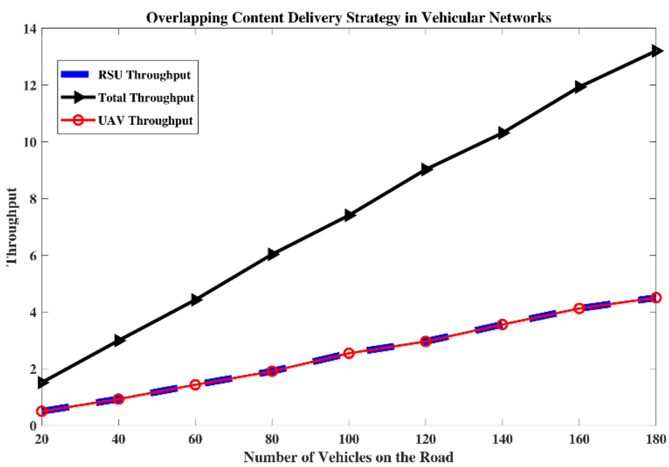

Fig. 5. Throughput with overlapping between RSU and UAV

Results shown in Fig. 4 in the context of content distribution with overlap between RSU and UAV show an intriguing phenomena. It is obvious that the entire amount of content delivered exceeds the sum of the individual amounts of content delivered by RSU and UAV. This finding emphasises how well resources are used by demonstrating non overlap between RSU and UAV as discussed earlier in our coordinated methodology in sub-heading A of result section.. Additionally, the matching throughput, as shown in Fig. 5, supports the equitable content delivery by both RSU and UAV but not equall to the total required content and required throughput, highlighting the effective use of our coordinated methodology as discussed in sub-heading A of result section. This result demonstrates the potential for intelligently regulating the interaction between RSU and UAV to optimise content delivery in vehicle networks.

V. Conclusion and Future Work

In conclusion, our study offers a tactical strategy utilising RSUs and UAVs to overcome the difficulties of content distribution in crowded vehicle networks. We maximise the efficiency of content distribution through efficient interference control, channel allocation, and resource distribution. Our method guarantees a smooth handoff between RSUs and UAVs in the absence of overlap, delivering complete required content and throughput. In contrast, when taking into account overlap, the combined content delivery by RSU and UAV follows the required content and throughput. By enabling intelligent cooperation between RSUs and UAVs in urban settings, our study lays the groundwork for improving content delivery in vehicle networks.

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