

UAV-Assisted Vehicular Communication for Densely Crowded Environments

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Abstract—Connected and Autonomous Electric Vehicles (CAEVs) are becoming a feature of our roads in the imminent future. This disruptive technology is likely to enhance the way we get around the city in many ways by collecting accurate data in regards to the surrounding environment and events in a timely-manner. As such data that is time-sensitive where human life may be at risk requires reliable and on-time data delivery. In crowded dense environments, several issues can reduce the network performance due to the high density of objects such as skyscrapers and vehicles as well as the large number of exchanged data between connected vehicles and other objects on the road. Involving a swarm of autonomous Unmanned Aerial Vehicles (UAVs), namely drones, would enhance network connectivity, reduce CAEVs communication delay, facilitate CAEVs tasks distribution, and elevate provisioning services. In this paper, a routing scheme in an autonomous UAV-connected vehicles network is proposed that provides reduced communication delay. The proposed solution has been evaluated using simulations. The collected results show the feasibility and the advantage of the UAV-assisted connected vehicle network in meeting delay and energy consumption requirements.

Index Terms—Connected Vehicles, UAV, Data Routing, ITS.

I. INTRODUCTION

Advances in artificial intelligence and machine learning has pushed the boundaries of smart cities in a remarkable way to improve quality of life and efficiency of urban operations and services, while meeting economic, social, and environmental needs of its dwellers. Connected, Autonomous and Electric Vehicles (CAEVs) have the potential to expedite the realization of a smart city especially in densely crowded cities [1]. The introduction of CAEVs to the road is an innovative solution to make the streets safer, enhance the traffic and introduce new transport services [2]. Based on the convergence of three disruptive technologies, namely, wireless connectivity, automation and electrification, CAEVs are able to provide self-driving, sharing and storing of digital content, sensing and monitoring its surroundings, and mobilizing electrical power. These capabilities can be translated into resource management services (e.g. traffic management, and Mobility as a Service (MaaS)) and crowd sensing services (e.g. sensing environment and pollution). CAEVs do not simply provide a like-for-like replacement for private, human-driven cars. All these services

are made possible thanks to a CAEV-nourishing stream, namely CAVs' connectivity, automation, and electrification. The connectivity stream covers the latest advancements and various technologies on vehicle-to-everything (V2X) communications/networking and vehicular cloud computing, with special emphasis on their role towards vehicle autonomy and smart cities applications. On the other hand, the autonomy stream is based on the latest advancements on decision-making solutions for safe maneuvers in complex driving environments using the information shared by all the vehicles and objects on the road. Connectivity and data delivery are critical concerns for autonomous vehicles. CAEVs are equipped with an important processing power to make crucial decisions based on sensory input shared by several vehicles and objects on the road. Such intelligent functions requires a prominent level of reliability and delay efficiency of the gathered data to make the best reactions on time, and that can be a critical issue in crowded environments that are full of obstacles such as skyscrapers, vehicles, trees, pedestrians, and much more.

To meet the expectations of CAEV users and provide better quality of service (QoS) and quality of experience (QoE), this paper proposes to involve a swarm of UAVs to collaborate with the connected land vehicles. Indeed, including a swarm of collaborative UAVs in a dynamic environment [3], can result in better connectivity, visibility of the area, monitoring and understanding of the situation, and, hence, smarter decision making and better support of various applications (e.g. traffic management, weather condition progress, parking availability) that may lead to new services such as emergency situation management, city safety, and flying taxis. However, these advantages may face some challenges, mainly, related to UAV energy constraints that reduces significantly the network lifetime and capacity. CAEVs require continuous gathering of reliable sensed data from other vehicles and objects on the roads on time. Such data is the pillar for crucial decision making in a very dynamic environment where human lives may be at risk and hence is time-sensitive. We propose to benefit from the flexibility and the easy movement feature of UAVs to provide delay-sensitive a data dissemination scheme taking into consideration UAV energy constraints.

The main contributions of the proposed solution are as follows:

- Define a novel routing scheme in UAV-assisted connected vehicle networks for delay-sensitive data that reduces UAVs' energy consumption.
- Evaluate the proposed solution through simulation tests to compare two proposed data delivery techniques against two other traditional data delivery techniques based on several performance metrics such as data delivery delay and node energy consumption.

The remainder of this paper is organized as follows: Section II presents some related work on UAV and connected vehicle networks. The detailed solution overview and its mathematical model are presented in Section III. Section IV presents and discusses the simulation results performed using NS-3. Finally, Section V concludes the paper with some possible future directions.

II. RELATED WORK

Several researchers have been focusing on involving UAVs with vehicles to provide various services such as better connectivity and car movement detection.

In [4], the authors focused on the quality of communications between flying UAVs and cars. They proposed a simulation framework that was used to evaluate the communication link between the ground and aerial vehicles in rural environments with low car densities. The communication link was evaluated based on various aircraft altitude and antenna orientation. In [5], the authors proposed a routing protocol for a Vehicle to Infrastructure (V2I) network based on transmission delay using UAVs in a two-way highway with low vehicular density. The UAVs in this paper are considered as infrastructure entities that replaces infrastructure Road Side Units (RSUs). To improve car-to-car communication, an investigation to use small mobile cells on the road was investigated in [6], and in [7] authors proposed to deploy these small cells, in addition to UAVs to cover vehicle hot-spots. Moreover, with the help of UAVs; CAEVs have the possibility to support vehicles to avoid rear-end collisions when drivers are distracted or tailgating [8].

Other researchers have elaborated on the UAV positioning issue to enhance the network performance. In [9], authors focused on using UAVs as support for vehicular communication, to relay data between cars. A positioning strategy was proposed to find the optimum position of the UAVs based on the signal strength received by the cars on the ground using the Received Signal Strength Indicator (RSSI) metric. This strategy is designed for a rural area with different terrain levels, where the density of cars and the interference are very low. Also in [10], another plan based machine learning was designed to find optimum UAV positions in emergency conditions to provide maximum data throughput.

Authors in [11], designed a dynamic mobility model for UAVs to maintain good coverage levels in terms of communication with moving ground vehicles and in [12], the authors proposed a general mobility model based on real UAV movements.

III. SOLUTION OVERVIEW

One of the requirements of the CAEV technology is to share accurate data with all the participants on time. In a

crowded city, where various obstacles are everywhere, data dissemination may face several challenges related to the big number of transmissions, multiple reflections and obstacles. Based on the ease of mobility nature of UAVs, the network may benefit from new shorter data routing paths to transmit data from any source node to any destination node in the crowd with shorter delays. Figure 1 provides an illustrative overview of the considered problem and solution. Such a solution also enhances the reliability of the received information, since it is transported far from the interference caused by the multiple transmissions initiated by cars and other objects on the ground level. A challenging constraint should be taken into consideration when designing a UAV-assisted connected vehicle network is the power limitations of UAVs, which may considerably reduce the network lifetime.



Fig. 1. CAEVs and UAVs in a densely crowded environment.

Given a network topology with UAVs and land vehicles, for a given source-destination communicating vehicles located on different streets, our objective is to find the appropriate route with minimum number of UAVs (equivalently, minimizing the energy consumed by the UAVs) such that a given delay requirement (D_{th}) is satisfied (transmission delay $\leq D_{th}$).

A. The Proposed Routing Algorithm

We note here that involving UAVs can provide less delay (fast delivery of information) but can significantly shorten the network lifetime as the UAVs are battery-powered energy-limited devices [13]. This can be achieved by performing two phases: (1) route discovery and (2) route selection.

1) *Route Discovery Phase*: To establish a route between a given source-destination vehicles (V_S and V_D), V_S sends flooding Route REQuest (RREQ) packets in the network (UAVs and vehicles) until reaching the destination. When V_D receives the first RREQ, it starts a time-out timer to receive RREQ packets and identify the set of feasible paths $\mathcal{P}$ between the communicating vehicles, where those paths may include UAVs and vehicles. After the timeout, the delay of each path $p \in \mathcal{P}$ along with the UAV-path-degree are determined (referred to as d_p and DEG_p , respectively). The UAV-path degree (DEG_p) is defined as the number of UAVs in a given path. As noted before, minimizing the UAV-path degree can reduce the energy consumption by the UAVs, resulting in extending the lifetime of the network.

2) *Route Selection*: Given d_p and DEG_p for each path $p \in \mathcal{P}$, the destination vehicle eliminates all paths with delay that is $> D_{th}$, resulting in the set of feasible paths $\mathcal{P}_F$. Then, it selects the path with the minimum node degree ($p^{\min}$) as defined in Equation (1).

$$p^{\min} = \arg \min_{p \in \mathcal{P}_F} \{DEG_p\}. \quad (1)$$

If several paths have the same DEG_p , we select the one with less delay. The pseudo-code of the proposed channel assignment and route selection algorithm is provided in Algorithm 1.

Algorithm 1 The Proposed Routing Algorithm

Input: $V_S, V_D, \mathcal{P}, V_S, D_{th}, DEG_p$, and $d_p, \forall p \in \mathcal{P}$
Output: Feasible route selection ($p^{\min}$) (or no feasible path)
Let $\mathcal{P}_F$ be the set of all feasible paths
 $\mathcal{P}_F = \phi$
for $p \in \mathcal{P}$
 if $d_p \leq D_{th}$
 Update $\mathcal{P}_F$ ($\mathcal{P}_F \leftarrow \mathcal{P}_F + \{p\}$)
 end-if
end-for
if $\mathcal{P}_F \neq \phi$
 $p^{\min} \leftarrow p^{\min} = \arg \min_{p \in \mathcal{P}_F} \{DEG_p\}$.
 if $|p^{\min}| \neq 1$
 Identify the path p^* with the smallest delay d_p
 $p^{\min} \leftarrow p^{\min} = p^*$.
 end-if
else $p^{\min} \leftarrow \phi$
end-if
if $p^{\min} = \phi$ return “no feasible path found”
else return $p^{\min}$
end-if

IV. SIMULATION RESULTS

Simulations were conducted using NS-3 to test and validate the proposed solution against traditional vehicular communication schemes. The environment consisted of up to 100 mobile nodes (representing vehicular nodes) and up to 20 access points (representing UAVs). The UAVs are randomly redistributed to mobile node dense locations throughout the simulation environment at predefined time intervals. Such a scheme would represent the movement of UAVs to locations of high-dense vehicular networks to aid in the process of all-time connectivity and faster data delivery/service responsiveness. The size of the considered network area was set to 1500m x 1500m. The UAVs are represented as 802.11g access points with a bandwidth of 54 Mbps. One next generation node B (gNB) base station is placed to cover the entire simulation environment with a bandwidth of 1 Gbps. Mobile nodes are equipped with three interfaces to allow them to communicate directly with each other (i.e. device-to-device) and with the WLAN access points and LTE base station (i.e. device-to-node). The communication distance for device-to-device was set to 50m and for device-to-node it was set to 100m.

We assumed that the transmission power usage for the base station, UAVs, and mobile nodes is set to 0.1W, 0.1W, and 0.01W, respectively. Two tests were conducted, namely, data

delivery delay and node energy consumption by comparing four different solutions (as illustrated in Figure 2), namely, pure vehicle-to-vehicle communication without the aid of UAVs nor base stations (V2V), vehicle-to-vehicle communication with the aid of the LTE base station (V2B), vehicle-to-vehicle communication with the aid of UAVs only (V2D), and vehicle-to-vehicle communication with the aid of both the UAVs and the base station (V2N).

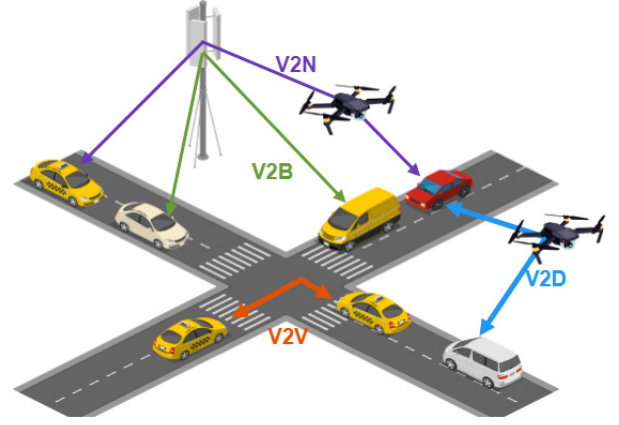


Fig. 2. Data communication and delivery techniques.

A. Data Delivery Delay

As discussed earlier, we assumed that data may be delivered in four different ways. Figure3 depicts a comparison of the overall average delay accumulated in sending data from vehicular node to another one as the node density in the simulation environment increases. Results show that the proposed V2N solution outperforms the other three in both low and high densities, with a larger difference in high density environments. When comparing traditional V2V communication to the proposed solution (i.e. V2D and V2N), we see that V2D outperforms V2V by reducing the overall data delivery delay by 48%. When comparing V2N to V2V, we see that V2N outperforms V2V by reducing the overall delay by 63%. It is important to note that in V2N the solution relies entirely on the UAVs for data routing and delivery. On the contrary, in V2N, the solution relies on both the UAVs and the LTE base station whenever all the UAVs are occupied with other data delivery requests. Moreover, results show that relying entirely on cellular communication for delivering data from one vehicle to another (i.e. V2B) does not dramatically reduce the overall delay when compared to V2D and V2N.

B. Energy Consumption

The energy consumption for data transmission of the proposed vehicular data delivery scheme is evaluated, where results are depicted in Figure 4 for a network density of up to 100 vehicular nodes. For the traditional vehicular communication solution, namely V2V, we see that the overall energy consumption is the highest compared to all other methods. This is due to the fact that all data transmissions and routing are performed by the vehicular nodes only. We see that by

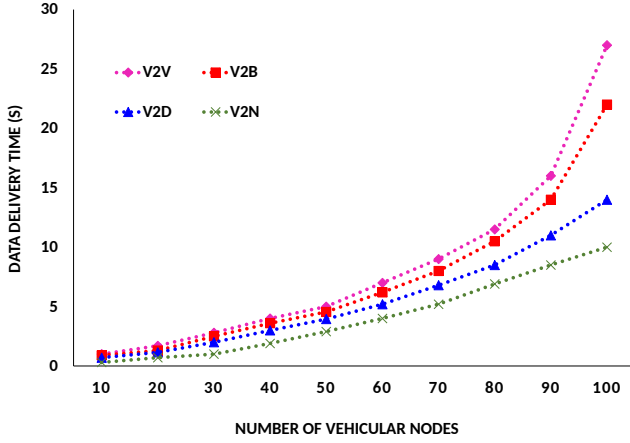


Fig. 3. Comparing the average data delivery delay among the four different techniques.

adapting the proposed solution, namely V2D, if all the routing and data transmission is performed by the UAVs without the aid of the cellular base station, then most of the energy consumption is transferred to the UAV side, while vehicular nodes consume much less energy. Finally, using the V2N solution, energy consumption by the UAVs is dramatically reduced due to the help of the cellular base station whenever all the UAVs are occupied with other data delivery requests.

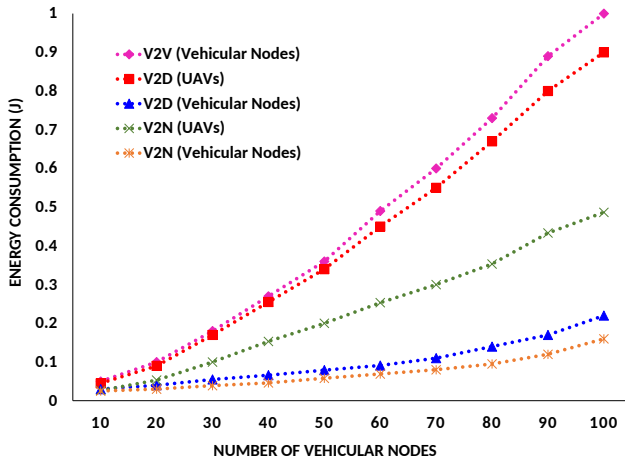


Fig. 4. Comparing the overall energy consumption for data transmission at an instance among three different schemes.

V. CONCLUSION

This paper introduced a new vehicular data delivery technique that relies on the use of UAVs. The solution primarily relies on power-limited UAVs to deliver data from a source CAEV to a destination CAEV. The solution is adopted for time-sensitive applications within highly dense smart city environments. Two approaches are used, namely, routing with complete reliance on UAVs and routing with reliance on

UAVs and traditional cellular communication such as 5G. The later is used to optimize the life of the network given the power-limited nature of UAVs. Moreover, optimal UAV data routing paths are selected to prolong the life of the network by reducing the number of UAVs used for data delivery. Simulations were conducted to test the proposed two solutions against traditional vehicular communication solutions such as Vehicular Ad-hoc Networks (VANETs) and cellular communication solutions such as 5G. Results show that the proposed solutions outperform traditional solutions in terms of data delivery delay and energy efficiency.

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REFERENCES

- [1] M. Aloqaily, I. Al Ridhawi, H. B. Salameh, and Y. Jararweh, "Data and service management in densely crowded environments: Challenges, opportunities, and recent developments," *IEEE Communications Magazine*, vol. 57, no. 4, pp. 81–87, 2019.
- [2] A. A. Alkheir, M. Aloqaily, and H. T. Mouftah, "Connected and autonomous electric vehicles (caevs)," *IT Professional*, vol. 20, no. 6, pp. 54–61, Nov 2018.
- [3] O. Bouachir, M. Aloqaily, F. Garcia, N. Larrieu, and T. Gayraud, "Testbed of qos ad-hoc network designed for cooperative multi-drone tasks," in *Proceedings of the 17th ACM International Symposium on Mobility Management and Wireless Access*, ser. MobiWac '19. New York, NY, USA: Association for Computing Machinery, 2019, p. 89–95. [Online]. Available: <https://doi.org/10.1145/3345770.3356740>
- [4] S. A. Hadiwardoyo, C. T. Calafate, J. Cano, Y. Ji, E. Hernández-Orallo, and P. Manzoni, "Evaluating uav-to-car communications performance: From testbed to simulation experiments," in *2019 16th IEEE Annual Consumer Communications Networking Conference (CCNC)*, Jan 2019, pp. 1–6.
- [5] H. Seliem, M. H. Ahmed, R. Shahidi, and M. S. Shehata, "Delay analysis for drone-based vehicular ad-hoc networks," in *2017 IEEE 28th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, Oct 2017, pp. 1–7.
- [6] S. Zafar, S. Jangsher, M. Aloqaily, O. Bouachir, and J. B. Othman, "Resource allocation in moving small cell network using deep learning based interference determination," in *2019 IEEE 30th Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)*, Sep. 2019, pp. 1–6.
- [7] L. Chiaraviglio, F. D'andreaiovanni, R. Choo, F. Cuomo, and S. Colonese, "Joint optimization of area throughput and grid-connected micro-generation in uav-based mobile networks," *IEEE Access*, vol. 7, pp. 69 545–69 558, 2019.
- [8] S. Khadim, F. Riaz, S. Jabbar, S. Khalid, and M. Aloqaily, "A non-cooperative rear-end collision avoidance scheme for non-connected and heterogeneous environment," *Computer Communications*, 2019. [Online]. Available: <http://www.sciencedirect.com/science/article/pii/S014036641930355X>
- [9] S. A. Hadiwardoyo, C. T. Calafate, J. Cano, K. Krinkin, D. Klionskiy, E. Hernández-Orallo, and P. Manzoni, "Three dimensional uav positioning for dynamic uav-to-car communications," *Sensors*, vol. 20, p. 356, 2020.
- [10] Lin, Adege, and Tarekegn, "Uav positioning for throughput maximization using deep learning approaches," *Sensors*, vol. 19, p. 2775, 06 2019.
- [11] S. Hadiwardoyo, J.-M. Dricot, C. Calafate, J.-C. Cano, E. Hernandez-Orallo, and P. Manzoni, "Uav mobility model for dynamic uav-to-car communications," 11 2019, pp. 1–6.
- [12] O. Bouachir, A. Abrassart, F. Garcia, and N. Larrieu, "A mobility model for uav ad hoc network," in *2014 International Conference on Unmanned Aircraft Systems (ICUAS)*, May 2014, pp. 383–388.
- [13] I. A. Ridhawi, M. Aloqaily, and A. Boukerche, "Comparing fog solutions for energy efficiency in wireless networks: Challenges and opportunities," *IEEE Wireless Communications*, vol. 26, no. 6, pp. 80–86, December 2019.