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▶ **To cite this version:**

Leila Bouchrit, Sajeh Zairi, Ikbal Msadaa, Amine Dhraief, Khalil Drira. Flying to the Rescue: UAV-Assisted Urgent Alert Transmission in VANET. IEEE International Conference on Enabling Technologies: Infrastructure for Collaborative Enterprises (WETICE 2023), Dec 2023, Paris, France. pp.1-6, 10.1109/WETICE57085.2023.10477830 . hal-04551024

HAL Id: hal-04551024
https://hal.science/hal-04551024

Submitted on 18 Apr 2024

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Flying to the Rescue: UAV-Assisted Urgent Alert Transmission in VANET

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Abstract

Safety applications are the cornerstone of the envisioned Vehicle Ad Hoc Network (VANET). Early transmission of alert messages following car accidents can avoid further potential crashes and save lives. However, the limited terrestrial coverage on highways, particularly in rural areas with low traffic density, hinders the deployment of this service. One promising solution involves integrating Unmanned Aerial Vehicles (UAVs), commonly known as drones, into VANETs to serve as flying relays. These UAVs can re-broadcast alert or warning messages between vehicles, bridging communication gaps. In this paper, we propose a unified UAVs-VANET architecture where UAVs relay messages among vehicles on rural highways. To evaluate our approach, we consider a case study involving a road accident on a Tunisian highway (Tunis - Bou Salem 75 km). We use the SUMO simulator in conjunction with NS3. The obtained results showed that 100% of vehicles are alerted within 3.85 seconds. The study also investigates how the number of deployed UAVs impacts the number of alerted vehicles.

Keywords: VANET, UAV, LTE/4G D2D, IEEE 802.11p

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1 Introduction

Permanent and reliable Vehicle-to-Vehicle (V2V) communication links are an indispensable prerequisite for transmitting messages among vehicles. These links convey warning messages between vehicles, including collision detection, emergency braking alerts, and traffic condition notifications. Particularly, during critical situations like accidents, the rapid delivery of safety messages can play a vital role in preventing emergencies. However, broadcasting an alert message between vehicles is a challenging task depending on the road condition, the vehicles density and the development of the country's terrestrial network. In scenarios such as a road accident at night with reduced traffic density or in rural areas lacking radio access infrastructure, only vehicles in the vicinity of the crash site will receive the broadcasted alert message.

In the same context, Tunisia, a middle-income country with limited 3G/4G network coverage [1], has witnessed a steady increase in accidents, rising from 5089 in 2021 to 5715 in 2022 [2]. Furthermore, during the first six months of 2023, there were 817 fatalities and 5286 injuries, which is alarming when considering the population rate. Timely receipt of alert messages could have potentially prevented these concerning statistics. To save lives, it is of the utmost importance to alert all vehicles within a few miles of a crash. A challenging issue is to achieve this in the presence of communication gaps among vehicles. The other point to consider is that warning messages must reach all vehicles on the highway in a short delay, allowing them to have enough time to react and prevent other accidents. Several studies suggest that, in safety applications, the maximum allowable end-to-end latency requirement between two User Equipment (UE) should not exceed 100 ms [3]. To meet these stringent service requirements, UAV assistance has been considered for monitoring traffic and providing timely warnings to drivers and travelers in the event of accidents. UAVs can also re-transmit emergency messages generated by crashed vehicles, even in the presence of communication gaps.

In this paper, we explore a UAVs-assisted VANET communication architecture for situations such as highway accidents where fixed communication infrastructure is limited or absent. We consider factors such as the number of UAVs, their positions, and altitudes as key inputs for our deployment model. The designed UAV-based architecture is developed to efficiently handle warning messages sent by the crashed vehicle, transmitting them via flying relays to distant vehicles. We conduct an extensive simulation study to determine the time required to alert 100% of vehicles and to investigate the impact of the number of UAVs on the percentage of alerted vehicles.

The rest of the paper is organized as follows: Section II provides a review of relevant literature works. Section III outlines our proposed system model. Section IV presents a detailed performance assessment of the proposed model. Finally, Section V concludes the paper.

2 Related work

UAVs-based VANET architecture is the core of several research efforts that consider various criteria, including enhancing network communications, expanding network coverage, or bridging communication gaps in rural areas. Tilahun et al. proposed a UAVs-based VANETs architecture in [4, 5], combining LTE/4G with WAVE as access technologies. The UAV senses tags and broadcasts vehicle information to the infrastructure or other vehicles. These messages relayed by the UAV are intended for safety and traffic applications. The proposed architecture aims to minimize vehicle bandwidth consumption to increase throughput, packet delivery ratio, and reduce delays. The authors have developed algorithms to optimize both UAV-to-Vehicle (U2V) and UAV-to-Infrastructure (U2I) transmissions based on the application type. In their scenario, they only involve a single UAV and have not considered the coordination of multiple UAVs to enhance the coverage of their proposed solution.

Following a similar principle, Raza et al. proposed a UAVs-based VANET architecture aimed at providing coverage to terrestrial users via UAVs, as described in [6]. In their work, UAVs function as relays, transmitting messages to adjacent UAVs and vehicles within their coverage area to bridge communication gaps. The authors focused on scenarios involving broadcasting emergency messages after vehicle collisions on highways, where the accident's geographical coordinates are an essential information for nearby vehicles. This allows any vehicle to determine its position relative to the accident and make appropriate decisions. The results demonstrated that warning messages were received by vehicles within the coverage area with reduced delays. However, it is s worth noting that the paper utilized mobile UAVs without specifying a coordination method among them, which may lead to potential issues in message transmission and notification to vehicles in the presence of communication gaps.

To enhance Vehicles-to-Infrastructure (V2I) communications, Shia et al. investigated the use of both single UAVs and UAV swarms to connect vehicles to terrestrial infrastructure, expand the network, collect network information, and provide additional accessibility resources for cars.

In Drone Assisted Vehicular Networks (DAVN) [7], UAVs serve as relay nodes to facilitate V2V communications by forwarding vehicle data. Additionally, UAVs function as Remote Radio Access Nodes (RRAN) to provide on-demand services and bridge coverage gaps based on traffic dynamics in space and time. To determine the appropriate UAV density for highways, Selim et al. [8] developed a closed-form expression for the probability distribution of Vehicle-to-UAV (V2U) packet delivery delay. This expression to adjust UAV placement based on highway conditions, considering factors like vehicle density and spatial distribution of traffic connections, with the aim of reducing packet delivery delays. For UAV flight trajectory control, Kawamoto et al. [9] introduced a reaction-diffusion model utilizing V2V communication to maximize information dissemination to vehicles.

Based on the reviewed literature, there is a gap in research concerning rural scenarios with low traffic where Road Side Units (RSUs) are absent. Addition-

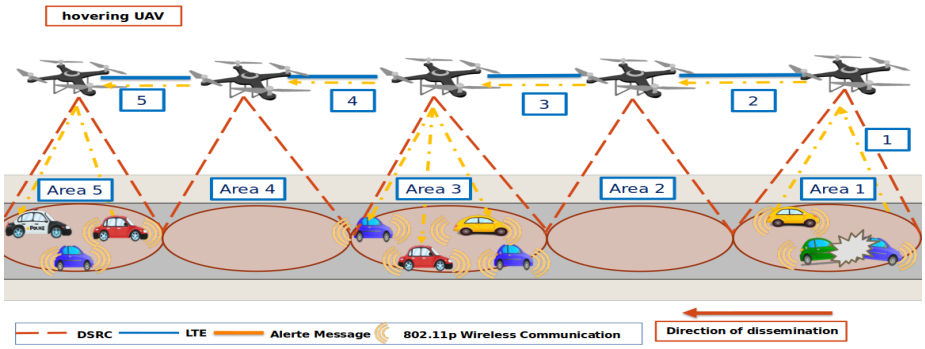

Figure 1: The proposed model

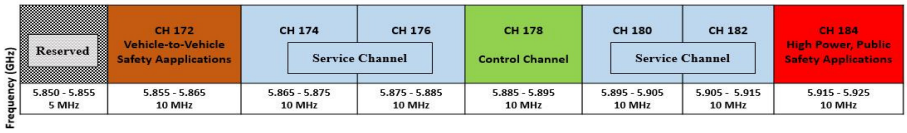

Figure 2: DSRC spectrum

ally, some prior works [5–7, 9] have not specified collision avoidance procedures for mobile UAVs, even though their proposals involve UAV mobility. Moreover, earlier studies [5, 7] utilized single or few UAVs, limiting their ability to assess the effectiveness of their solutions with multiple UAVs. To address these issues, our proposal focuses on the optimal deployment of UAVs on rural highways to relay crash notification messages. We employ UAVs as flying relays to bridge communication gaps and alert the maximum number of vehicles in the event of an accident.

3 System model

As mentioned earlier, in the case of a road accident on a rural highway with sparse traffic, only nearby vehicles become aware of it. Consequently, distant vehicles remain unaware of the accident and may not have enough time to react and prevent a potential collision. In Fig. 1, vehicles located in area 3 and 5, will be unaware of the accident until they reach the scene. To alert all vehicles on the highway, we propose using UAVs as flying relay retransmitting emergency notifications to distant vehicles. These UAVs will be positioned along the highway to bridge the gap between vehicles and deliver alert messages quickly, thereby preventing future collisions.

As shown in Fig. 1, the green car in area 1 broadcasts this alert message. This message is received by neighboring vehicles and the UAVs covering the section of the road where this car is located. Upon receiving the alert message, vehicles activate their alert management function. All vehicles are set up to receive alert

messages without the need for retransmission. However, when a UAV receives such a broadcast beacon, it forwards it to the preceding UAV via the Long Term Evolution Device-to-Device (LTE D2D) interface. For example, when receiving the alert message from the crashing car, the UAV 1, positioned beneath area 1, will relay it to its predecessor (UAV 2). Simultaneously, it rebroadcasts the received beacon to all vehicles within its coverage range using the IEEE 802.11p communication interface. This process repeats until all vehicles are notified of the accident.

For the proposed model implementation, several assumptions must be highlighted. In the following, we describe the aerial and ground component of our architecture.

3.1 Vehicle segment

For V2U and V2V communications, we adopt the Dedicated Short Range Communications (DSRC) technology [10]. The authorized spectrum allocated to DSRC is the 5.9 GHz band consisting of seven 10 MHz channels: six Service CHannel (SCH) and one Control CHannel (CCH) as illustrated in Fig. 2.

In safety applications, vehicles equipped with DSRC can broadcast and receive safety or awareness messages, including essential information such as direction, speed, location, or acceleration, within a range of hundreds of meters [10]. These messages are referred to as Basic Safety Messages (BSM) and are defined by the SAE J2735 DSRC Message Set Dictionary standard [11]. This standard specifies fifteen types of messages for use in VANET communications, with BSM (also known as a beacon) being the most critical message for safety applications, transmitted exclusively via the Control Channel (CCH). As illustrated in the table Tab. 1, it is composed of two parts: a mandatory part included in every BSM and containing vehicle status and an optional part added as needed. With the help of the information contained in the safety message, each vehicle can calculate its route or avoid any warning situation [10]. We also assume that all vehicles are equipped with On-Board Units (OBUs), and therefore, all V2V and V2I communications utilize the 802.11p protocol, which operates in both the PHY and MAC layers of DSRC.

3.2 Aerial segment

When considering UAVs, several criteria become relevant, including power consumption for extended endurance, optimal altitude for improved visibility and maximum coverage, enabling better wireless communication with neighbors in a shorter time, and more. Energy consumption is a significant challenge for UAVs' effectiveness and reliability. Battery-powered UAVs typically have a flight time of less than one hour, necessitating frequent returns for recharging [12]. For the purposes of this paper, we assume that all UAVs are equipped with rechargeable batteries. These batteries can be replenished through various means, such as solar energy, gasoline, electrical energy, and more [13].

Table 1: BSM format

Item type	Item type	Description	Bytes
Mondatary Part	msgID	DSRCmsgID	1
	MsgCnt	MsgCount	1
	id	TemporaryID	4
	secMark	DSecond	2
	lat	Latitude	4
	long	Longitude	4
	elev	elevation	2
	accuracy	PositionAccurarcy	4
	Speed	Speed	2
	heading	Heading	2
	angle	SteeringWheelAngle	1
	accelSet	AccelerationSetWay	7
	brakes	BrakeSystemStatus	2
	size	VehicleSize	3
Optional Part	Event flags Vehicle path history Vehicle path prediction RTCM package		

The optimal altitude of the UAV can enhance the probability of establishing Line of Sight (LoS) links with ground users [14] and provide maximum wireless communication coverage for vehicles. Path Loss (PL) due to obstacles and buildings is not a concern in our case since we consider a suburban/rural context, allowing vehicles and UAVs to communicate within visual LoS. To determine the optimal UAV altitude and improve air-to-ground PL, the authors in [14] proposed an air-to-ground path loss model for Low-Altitude Platforms (LAPs) (see Equation (1)). The Probability of LoS connection (P_{los}) occurring between a LAP and a vehicle, where LAP stands for a UAV that operates at relatively low altitudes above the ground, is defined by following equation (1).

$$P_{los} = \frac{1}{1 + e^{-b(\frac{180}{\pi}\theta - a)}} \tag{1}$$

Where θ is the elevation angle between the UAV and the vehicle, calculated as $\theta = \arctan\left(\frac{h}{r}\right)$, where h is the UAV altitude and r is the horizontal distance between the UAV and the vehicles, as shown in Fig. 3.

The parameters a and b are constants dependent on the environment (rural, urban, etc.). In the closed-form expression (1), the probability of achieving a clear Line of Sight (LoS) increases with the elevation angle θ. Therefore, for a fixed r, the probability of establishing a LoS connection between the UAV and vehicles improves with the correct altitude. Equation (2) represents the average Path Loss (PL) in the channel model for communication between the UAV and vehicles [14]:

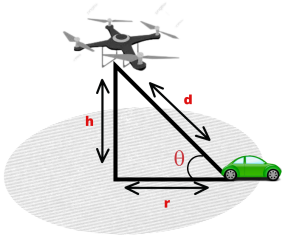

Figure 3: UAV-Vehicle path-loss model

$$\bar{PL} = 20\log_{10}(\frac{4\pi f_c d}{c}) + \eta_{LoS}P_{LoS} + \eta_{NLoS}P_{NloS} \tag{2}$$

Here, P_{NLoS} represents the probability of a Non-Line-of-Sight (NLoS) link and is defined as:

$$P_{Nlos} = 1 - P_{los} \tag{3}$$

Where c is the speed of light, f_c is the carrier frequency, d is the distance between the drone and the vehicle, calculated as $\sqrt{h^2 + r^2}$. η_{LoS} and η_{NLoS} depend on the environment and represent the average additional loss to free space propagation for LoS and NLoS connections, respectively. Therefore, selecting the appropriate altitude is essential for achieving better wireless coverage and visibility between UAVs and vehicles.

In addition to the embedded 802.11p in UAVs, we assume an out-of-coverage LTE Device-to-Device (LTE D2D) scenario for communication between the UAVs. LTE Proximity Services (ProSe) were introduced by the 3$^{\text{rd}}$ Generation Partnership Program (3GPP) [15], enabling direct communication between neighboring User Equipment (UEs). UEs establish communications through the Side Link (SL) or PC5 interface, and LTE D2D offers three key functionalities: direct communication, discovery, and synchronization. In direct communication, UEs exchange packets directly, bypassing the need to go through a base station or an evolved NodeB (eNodeB), which helps prevent network congestion. This is especially valuable in critical situations like road accidents, where LTE D2D can provide rapid service to drivers. The direct discovery feature allows UEs to share system information with neighbors without establishing a communication link. Lastly, the synchronization feature provides system information to nearby UEs to assist in decoding link transmissions.

Fig.4 illustrates three Device-to-Device (D2D) communication scenarios: in-coverage, out-of-coverage, and mixed coverage. In the in-coverage scenario, UEs automatically connect to the network. In the out-of-coverage scenario, they utilize preconfigured parameters for autonomous operation. In the mixed coverage

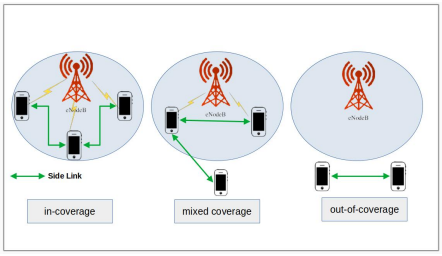

Figure 4: LTE D2D communication scenarios

scenario, UEs connected to the network serve as relays for those without coverage. LTE D2D offers advantages such as lower delays and greater power savings compared to Wi-Fi usage [16].

In our proposal, each vehicle and UAV implements specific algorithms for processing received alert messages. The first algorithm involves how a vehicle treats received BSM. When a vehicle receives a warning message for the first time, it activates its alert management function; otherwise, it ignores the message. The second algorithm handles the processing of warning messages by UAVs. If a warning message originates from another neighboring UAV, the receiving UAV rebroadcasts it to all vehicles within its communication range and to its own predecessor UAV. This process continues until all vehicles on the highway are notified of the crash and take appropriate precautions. These algorithms are detailed in the following (see Algorithm 1 and 2).

Algorithm 1 Processing of a BSM message by a vehicle

1: **if** The BSM is received for the first time **then**
2: Enable alert management function
3: **else**
4: Drop the message
5: **end if**

Algorithm 2 Processing of a BSM message by a UAV_i

1: UAV_i retransmits the BSM to UAV_{i-1} through the LTE D2D interface
2: **if** The BSM is not received from the crashed car **then**
3: UAV_i broadcasts the alert message to all vehicles in its range through the IEEE 802.11p interface
4: **end if**

4 Results

4.1 Simulation environment

This section outlines the simulation results of the proposed model. The proposed model was implemented in NS3 (version 3.35). In addition, we imported the

Table 2: Parameters setting

Simulator	Parameter	Value
SUMO	Highway length	75 km
	Number of lanes	2
	Vehicles number	100
	Vehicle speed	30 m/s
	Inter-vehicle time	5 s
	Silence time	200 s
	Accident event	2485s
	Accident geographical position	73500 m
	Simulation duration	3000 s
ns3.35	Message Type	BSM
	UAVs number	55
	Distance between UAVs	1350 m
	Simulation duration	3000 s

Figure 5: Tunis - Bou Salem highway

map located between Tunis and Bou Salem (cf. Fig. 5.) from Open Street Map (OSM) [17] into the SUMO Simulator to generate realistic vehicular mobility patterns. In this mobility model, a bi-directional highway segment of 75 Km was considered. 100 vehicles were sequentially injected into the highway. Inter-vehicle time is defined as the time between two consecutive vehicles traveling on the same lane in the highway. In the context of the proposed model, silence time between two sets of vehicles entering the highway, refers to the time that should elapse between the last vehicle in the first set and the first vehicle in the second set. Tab. 2 summarizes the configuration settings used in the simulation.

All vehicles are equipped with an IEEE 802.11p interface operating at 5.9 GHz with a transmission power level of 22 dBm. The IEEE 802.11p protocol enables communication over a range of 1000 m between vehicles. The vehicle-to-vehicle propagation model is based on the Friis propagation loss model with a constant speed propagation delay.

The relationship between UAVs and vehicles is determined by Equation 2. The channel has a transmission speed of 6 Mbps and a bandwidth of 10 MHz. In our model, UAVs hover at fixed positions along the highway with a separation

distance of 1350 m between two successive UAVs, and their altitude does not exceed 300 m.

Each UAV is equipped with two communication interfaces: IEEE 802.11p and LTE/4G D2D. The first interface is used to communicate with the associated vehicles, while the LTE D2D interface is used for inter-UAVs communication, with a transmission power of 23 dBm. The chosen propagation model for communication between UAVs is the Cost 231 Propagation Loss Model. Downlink Evolved Universal Radio Access (E-UTRA) Absolute Radio Frequency Channel Number (DlEarfcn) and Uplink E-UTRA Absolute Radio Frequency Channel Number (UlEarfcn) parameters are used in LTE to define specific frequency carriers for downlink and uplink transmission, respectively. The DlEarfcn value stands at 5280, whereas the UlEarfcn value is 23280. The Uplink Bandwidth (UlBandwidth) is defined as 50 MHz, representing the allocation of a specific number of Resource Blocks (RBs) for Uplink transmission.

We examined two scenarios to assess the effectiveness of our proposed model. In the first scenario, which represents the ideal case, the entire highway is covered by UAVs, and there are no communication gaps. We measured the time required for all vehicles to receive BSM messages and determined the number of vehicles that became aware of the accident at each delay interval. In the second scenario, we deactivated some UAVs and observed the average number of alerted vehicles as a function of the number of deactivated UAVs.

For each scenario, we conducted 10 simulation runs and calculated their 95% confidence intervals. To evaluate the performance of our model and precisely measure the time it takes for all vehicles to be notified of the crash, we considered two parameters:

- The number of vehicles served per time unit (second), which calculates the number of vehicles that received a BSM after a specific delay.
- The number of served vehicles as a function of the number of deactivated UAVs.

4.2 Simulation results

Fig. 6. shows the performance of our scenario in terms of the number of vehicles notified after each time unit. Fig. 6. also shows that all vehicles were notified of the accident after 3.85 seconds, which is a small delay given the size of the network. Note that only the crashed vehicle and the UAVs are rebroadcasting the BSM which considerably reduces the network overhead. These short delays can be explained by the fact that UAVs cover the entire highway. Accordingly, there are no communication deficiencies in the network. Therefore, at any moment and if there are problems such as car collisions or traffic jams, all vehicles will be aware of the event in order to react positively. The UAV relay function plays an important role in closing the communication gap that may occur between vehicles. In addition, with the use of LTE D2D, the UAV can transmit data directly to its neighbor without going through an eNodeB. Especially in critical situation such as accident or traffic jams, if drivers are alerted beforehand, they

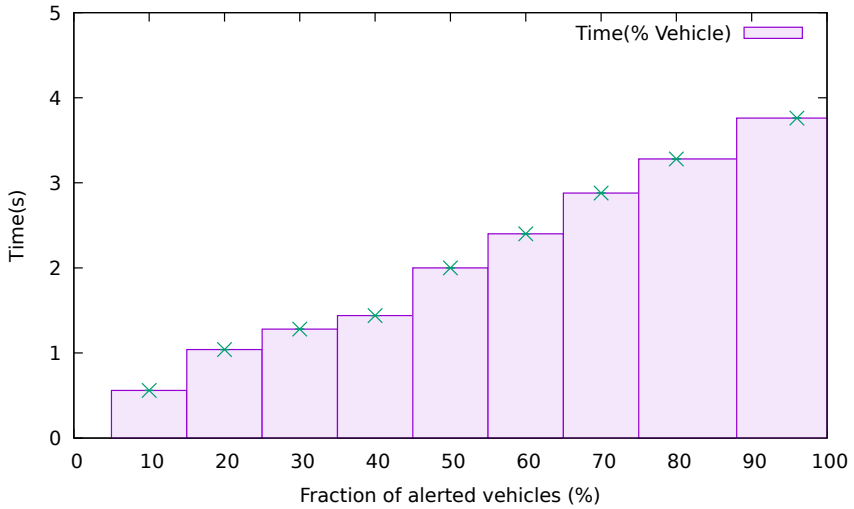

Figure 6: Fraction of alerted vehicles as a function of time

can react correctly. This point, LTE D2D, is also an advantage of the proposed model as there is no need for a costly infrastructure.

In the second scenario, UAVs are deactivated according to a uniform distribution. We have respectively deactivated 10, 20, 30, 40 and 50 per cent of the UAV and determined the number of vehicles notified by the accident event. Fig. 7. shows that if a relay UAV is turned off, the number of alerted vehicles goes down. Indeed, the communication deficiency arises and therefore many vehicles will be unaware of the accident. From this observation, we can conclude that UAVs play a very important role in connecting a network especially when the cost of deploying a terrestrial infrastructure is prohibitive. In such a case, a UAV-assisted VANET could be a cost-effective option to support. Based on previous observation, we conclude that more efforts should be put to consider the case where the highway is not totally covered by fixed UAVs. The solution to this situation is that UAVs test their respective reachability, and in case of unavailability, they trigger their mobility. This will be the subject of a future work.

5 Conclusion

This work focuses on UAV assistance for VANET, specifically in transmitting alert messages when communication gaps exist between vehicles. Our proposed solution is applicable even in the absence of fixed infrastructure, which is a significant advantage. Simulation results demonstrate that all vehicles can be alerted quickly. Additionally, our model reduces network overhead by minimizing the need for all vehicles to re-transmit BSMs, which is another notable advantage. Only a limited number of vehicles retransmit BSMs. This model

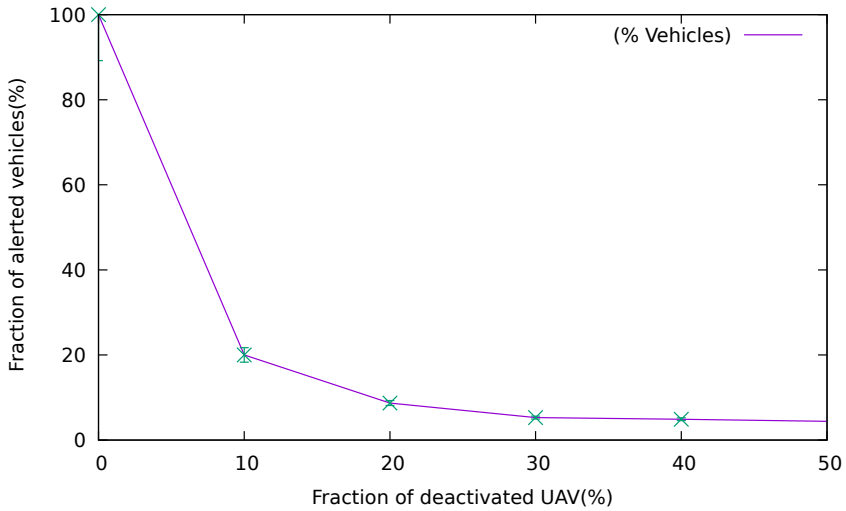

Figure 7: Fraction of alerted vehicles as a function of the fraction of deactivated drones

serves as a foundation for future research exploring VANET assistance with a reduced number of UAVs.

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