Delay Analysis for Drone-Based Vehicular Ad-Hoc Networks

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Delay Analysis for Drone-Based Vehicular Ad-Hoc Networks

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Abstract**—Using Unmanned Aerial Vehicles (UAVs) or drones in Vehicular Ad-hoc Networks (VANETs) has started to attract attention. This paper proposes a mathematical framework to determine the minimum drone density (maximum separation distance between two adjacent drones) that stochastically limits the worst case for the vehicle-to-drone packet delivery delay. In addition, it proposes a drones-active service (DAS) that is added to the location service in a VANET to obtain the required number of active drones based on the current vehicular density while satisfying a probabilistic requirement for vehicle-to-drone packet delivery delay. Our goal is boosting VANET communications using infrastructure drones to achieve the minimum vehicle-to-drone packet delivery delay. We are interested in two-way highway VANET networks with low vehicular density. The simulation results show the accuracy of our mathematical framework and reflect the relation between the vehicle-to-drone packet delivery delay and the drone density.**

I. INTRODUCTION

Vehicular ad-hoc network (VANET) technology enables ad-hoc communication between vehicles, or vehicles and road-side units (RSUs). Many vehicle manufacturers have equipped their new vehicles with global positioning systems (GPSs) and wireless communication devices. In addition, the United States Federal Communications Commission (FCC) has allocated 75 MHz of the radio spectrum at 5.9 GHz to be used by Dedicated Short Range Communications (DSRC) [1]. One of the most important goals of VANETs is to provide safety applications for passengers. In addition, VANETs provide comfort applications to users (e.g., mobile e-commerce, and weather information).

Many papers have proposed their solutions for vehicle-to-infrastructure (V2I) communications based on static infrastructure-RSUs. For instance, a probabilistic vehicle-to-RSU packet delivery delay model was proposed in [2]. The model is based on effective bandwidth theory and the effective capacity concept in order to obtain the maximum distance between infrastructure-RSUs. In addition, the authors in [3] proposed a mathematical framework for the vehicle-to-RSU packet delivery delay distribution based on the distance between RSUs. However, they did not consider RSU wireless communication in the model. Moreover, [4] proposed an optimal infrastructure-RSU-placement model for hybrid VANET sensor networks. It formulates the problem as an integer linear-programming optimization problem and then applies the center particle swarm optimization approach.

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Unmanned aerial vehicles (UAVs) or drones are semi-autonomous or fully-autonomous unmanned aircrafts that are equipped with communication devices. Integration of UAVs in wireless communication systems has started to attract attention. For instance, drone-base-stations (drone-BSs) can be used as in cellular wireless networks, as in [5]. Using drones with cellular networks as aerial base stations provides dynamic deployment ability. Drone-cells offer service where the demand exists. The drone-cell size depends on many parameters (e.g., UAV altitude, environment, spectrum frequency, and the transmitted power).

Many papers have proposed integrating drones in wireless communication. However, only a few papers have proposed using drones in VANET networks. For instance, VDNet [6] was proposed as a routing protocol for vehicle-to-vehicle (V2V) communications based on drones to decrease the average end-to-end packet delivery delay. Some vehicles in VDNet are equipped with an on-board drone, which can deliver data messages directly to the destination, relay messages in a multi-hop route and collect location information while flying above the traffic.

Connectivity-based traffic density aware routing using UAVs for VANETs (CURVE) [7] was proposed as a routing protocol for VANETs using drones through cooperative and collaborative communication. It is based on information exchange between vehicles and drones to select the most appropriate next intersection to deliver the data packets successfully to their destinations.

In addition, the intersection UAV-assisted VANET routing protocol (UVAR) [8] was another proposed a routing protocol for VANETs with drones. It uses the drones to collect information about the traffic density on the ground and the state of the vehicles' connectivity, and exchange this information with vehicles through "Hello" messages. Moreover, UVAR uses drones as a relay when connectivity between vehicles on the ground is not possible.

This paper proposes a V2I communications routing protocol where we replace infrastructure-RSUs with infrastructure drones. As drones represent gateways to the Internet and the infrastructure of other systems such as the intelligent transport system (ITS), vehicles can transmit their real-time information and Internet requests to the infrastructure drones. However, it is difficult, in terms of infrastructure cost, to cover all gaps in the highway to get VANETs with full connectivity. On the other hand, using a small number of drones causes long vehicle-to-drone packet delivery delays, especially in low vehicular density scenarios. This is because the vehicles use the carry-and-forward strategy until reaching the next drone to overcome network disconnection with low vehicular density. Our objective in this paper is to analyze the vehicle-to-drone packet delivery delay in VANETs with low vehicular density where the sensed data is destined to the infrastructure drones.

The vehicle-to-drone packet delivery delay distribution offers a design tool that can determine the maximum separation distance between two adjacent drones or the minimum number of drones required to cover a two-way highway road while satisfying a probabilistic requirement of vehicle-to-drone packet delivery delay. Moreover, it can used for the optimization of drone placement. The proposed analytical framework takes into account the likelihood of a carrier vehicle exiting the road at any road junction, the spatial distribution of road junctions, the drone communication range, and the vehicular density over the highway.

The main contributions of this paper are as follows: 1) it analyzes the drone wireless communication range in the VANETs and proposes a routing protocol for using infrastructure drones in VANET communications, 2) it proposes a mathematical framework for characterizing the vehicle-to-drone packet delivery delay distribution for the proposed protocol, 3) it proposes an algorithm to calculate the required number of active drones based on the current vehicular density while satisfying a probabilistic requirement for vehicle-to-drone packet delivery delay, and 4) It compares results from the proposed mathematical framework with simulation results to show the accuracy of our analysis.

The rest of this paper is organized as follows. Section II introduces the system model. Section III discusses the drone wireless communication range in VANETs. Section IV presents the problem formulation and the analytical analysis for characterizing the vehicle-to-drone packet delivery delay distribution. In addition, Section V proposes a drones-active service. Next, Section VI compares the simulations results against analytical results. Finally, the conclusions and future work are presented in Section VII.

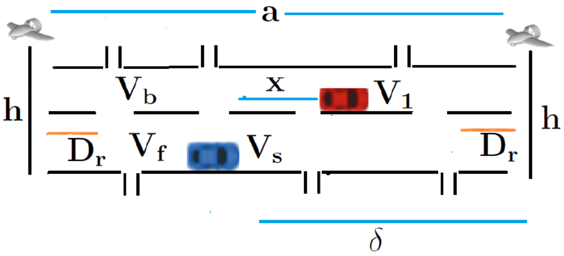

Fig. 1. System model.

II. SYSTEM MODEL

As shown in Fig. 1, we consider a two-way highway segment with vehicles moving in one of two opposite directions. Each lane is a straight line with a fixed length of a meters and has two drones at its ends. In addition, δ is the distance that the vehicle travelled while carrying the packet before forwarding to the next drone. While, vehicles are moving in the forward direction with a constant speed V_f, vehicles are moving in the opposite direction with a constant speed V_b. The constant speed assumption over the observation period helps to investigate the worst case scenario in V2Is where vehicles moving in one direction have the same speed between two adjacent drones.

In addition, we assume that any moving vehicle is the source of packets and the destination is an infrastructure drone which has access to the Internet and other infrastructure systems. In addition, a vehicle acting as the packet source sends one replica of the packets in the opposite direction. Therefore, packets are carried either by their source vehicles or a carrier vehicle moving in the opposite direction. In the case of high vehicular density, a connected multihop vehicle-to-drone path can be found with a high probability; however, this case is out of the scope of the current work. Our analysis focuses on the worst case where the original packet is stored by its source vehicle until it is within communication range of a drone.

Moreover, consider road junctions distributed randomly on the highway as depicted in Fig. 1. Some vehicles may join and others may leave at any road junction along the highway. We assume that the number of road junctions within the highway follows a Poisson distribution with a parameter λ_c and a vehicle can leave the highway at any road junction with a probability P_c as assumed in [3].

Additionally, we assume the inter-vehicular distances between the vehicles are exponentially distributed [2] and the number of vehicles in each direction is Poisson-distributed with vehicular density N_f and N_b for the forward and backward directions, respectively. In a realistic VANET scenario, the vehicular density may change with time as the average number of vehicles entering the road segment may not be equal to the average number of vehicles leaving the road segment. Therefore, the drones can change their placement and the distance between each two drones while satisfying the probabilistic constraint of the vehicle-to-drone packet delivery delay may also change.

In addition, it is assumed that the VANET includes a location service such as a hierarchical location service (HLS) [9] or grid location service (GLS) [10]. Moreover, the transmission range between vehicles is assumed to be smaller than the distance between two adjacent drones. Moreover, we assume that the medium access control (MAC) layer protocol is the distributed coordination function (DCF) of the IEEE 802.11 standard. The packet traffic model follows the constant bit rate (CBR) pattern between a source vehicle and the infrastructure drone.

III. DRONE WIRELESS COMMUNICATION COVERAGE

There is a growing number of papers related to the wireless communication range of drone base-stations (BSs) in cellular networks. In [11], air-to-ground path-loss for low altitude platforms (LAPs), like drone-BSs at heights of less than 3000 meters, is modelled. The model shows that there are two main propagation categories, corresponding to the receivers with line-of-sight (LoS) connections and the ones without LoS connections which still receive the signal from LAPs due to strong reflections and diffractions.

The authors in [12] found the optimal altitude of a single drone-BS to obtain a required coverage while minimizing the transmit power. The probability of LoS is an important factor in modelling air-to-ground path-loss. In [13], a closed-form-expression for the probability of LoS connection between a LAP and a receiver is proposed and formulated as follows

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

where a and b are constant values depending on the environment (rural, urban, etc), and θ is the elevation angle that is equal to $\arctan(\frac{H}{R})$, where H and R are the drone's altitude and its horizontal distance from the vehicle, respectively. Eq. (1) shows that the probability of having a LoS connection is increased as the elevation angle increases. Therefore, with a fixed R, if the drone altitude increases, the probability of LoS will increase.

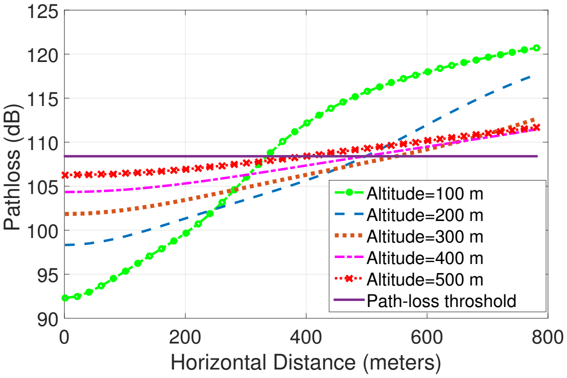

Fig. 2. Path-loss for different drone altitudes.

In addition, based on [13], the mean path-loss model for drone-to-vehicle propagation channel will be as follows

$$PL(dB) = 20\log\left(\frac{4\pi f_c d}{c}\right) + P_{LoS}\,\eta_{LoS} + P_{NLoS}\,\eta_{NLoS}, \tag{2}$$

where f_c is the carrier frequency, c is the speed of light, and the probability of non-LoS connection $P_{NLoS} = 1 - P_{LoS}$. In addition, d is the distance between the drone and the vehicle that is equal to $\sqrt{H^2+R^2}$, where H and R are the drone's altitude and its horizontal distance from the vehicle, respectively. Moreover, η_{LoS} and η_{NLoS} depend on the environment and they are the average additional loss to the free space propagation for LoS and NLoS connections, respectively. The wireless communication range for the drones in a VANET depends on the drone altitudes and the path-loss threshold in the VANET.

Based on Eq. (2), Fig. 2 shows the mean path-loss for drone-to-vehicle propagation channel against the horizontal distance between the drone and the vehicle for different drone altitudes 100, 200, 300, 400, and 500 meters where a = 9.6, b = 0.28 as in [12], and f_c = 5.9 GHz. In [14], the authors calculated the path-loss threshold for VANETs at f_c = 5.9 GHz and 750 MHz based on experimental results. The path-loss threshold for f_c = 5.9 GHz in [14] is 108 dB.

Therefore, we can obtain the drone wireless communication range at any altitude in Fig. 2 by the intersection point between the path-loss threshold line and the drone altitude line. It is noticed that the wireless communication range for a drone altitude of 100 meters is 340 meters. On the other hand, the wireless communication range for a drone altitude of 300 meters is 540 meters. However, the wireless communication range for a drone altitude of 500 meters is almost 450 meters. In addition, the optimal altitude is based on the path-loss threshold. For example, if we were to change the path-loss threshold to 112 dB, the optimal altitude would be at 400 meters and the range would be close to 790 meters.

The reason behind this behavior is that a low altitude increases the probability of NLoS than that of LoS, due to reflections by buildings and other objects, and the additional loss of a NLoS connection is higher than a LoS connection. However, when the altitude increases, the LoS probability increases as well and in turn path-loss decreases. On the other hand, the path-loss is also dependent on the distance between the vehicle and the drone. Therefore, after a specific height, the distance between the vehicle and the drone factor dominates and as the altitude increases, the path-loss increases as well.

IV. PROBLEM FORMULATION AND THE MODEL

Here, we follow the same analysis proposed in [3]. However, we also consider the drone wireless communication range in our analysis. Our objective is to obtain a closed form for the vehicle-to-drone packet delivery delay cumulative distribution function $F_T(t)$ in terms of a (the distance between each pair of adjacent drones), D_r (drone wireless communication range that depends on drone altitude and path-loss threshold) and vehicular density on the two-way highway road as shown in Fig. 1. Using this closed form, we can get the minimum number of drones (maximum a) that satisfies a certain delay constraint T_{max} with a violation probability of at most ε as indicated in Eq. (3).

$$\begin{aligned} &\text{maximize} \quad a \\ &\text{subject to} \quad 1 - F_T(T_{max}, a) \leq \varepsilon. \end{aligned} \tag{3}$$

For achieving a minimum delay, the source vehicle sends the packet in the forward and opposite directions (two replicas of the same packet) and considers the packet that reaches the infrastructure earlier. Therefore, we can formulate the problem as follows

$$Pr(T \leq t) = Pr(T \leq t, I = 1) + Pr(T \leq t, I = 0), \tag{4}$$

where T is a random variable representing the vehicle-to-drone packet delivery delay and I is a random variable representing the number of replicas of the packet. In the first case (I = 1), there is one replica of the packet and a source vehicle sends the packet in the forward and opposite directions. In the second case (I = 0), there is no replication of the packets and a source carrier vehicle sends the packet only in the forward direction.

First, we wish to get a closed form for the term $Pr(T \leq t | I = 1)$ (the conditional CDF of the vehicle-to-drone packet delivery delay given $I = 1$). We can express it as follows

$$Pr(T \leq t, I = 1) = Pr(T \leq t | I = 1) Pr(I = 1). \tag{5}$$

Fig. 1 shows that δ is between 0 and $(a - 2D_r)$. Therefore, we condition δ from 0 to $(a - 2D_r)$ as follows

$$\begin{aligned} Pr(T \leq t, I = 1) = \int_0^{\infty} \int_0^{a-2D_r} & Pr(T \leq t | I = 1, X = x, D = \delta) \\ & Pr(I = 1 | X = x, D = \delta) f(\delta, x) \; d\delta \;\; dx, \end{aligned} \tag{6}$$

where D is the distance between the source vehicle and the drone in the forward direction, X is the distance between the source vehicle and the first vehicle in the opposite direction, D_r is the drone communication range, and $f(\delta, x)$ is the joint probability density function (PDF) of δ and X. While the random variable D is uniformly distributed since the vehicle location is uniformly distributed over a, the random variable X is exponentially distributed since the vehicles form a Poisson process. As a result, we can obtain the expression for $f(\delta, x)$ as follows

$$f(\delta, x) = \frac{N_f + N_b}{a - 2D_r} e^{-(N_f + N_b)x}, \qquad 0 \leq \delta \leq a - 2D_r, x > 0. \tag{7}$$

In addition, the term $Pr(I = 1 | X = x, D = \delta)$ represents the probability that the packet carrier vehicle will not leave the highway at any road junction. We assume that the number of road junctions within the highway follows a Poisson distribution with a parameter λ_c and a vehicle can leave the highway at any road junction with a probability P_c. Therefore, the vehicle will leave the road segment within a distance of y with probability $P_l(y)$, where $P_l(y) = 1 - e^{-\lambda_c P_c y}$ as proposed in [3]. As a result, we can obtain the expression for this term as follows

$$Pr(I = 1 | X = x, D = \delta) = e^{-\lambda_c P_c (a - \delta - 2D_r + x)}. \tag{8}$$

The first term in Eq. (6) $Pr(T \leq t | I = 1, X = x, D = \delta)$ can be formulated as follows

$$\begin{aligned} & Pr(T \leq t | I = 1, D = \delta, X = x) = \\ & u\left(t - \min\left(\frac{a - \delta - 2D_r + x}{V_b}, \frac{\delta - D_r}{V_f}\right)\right), \end{aligned} \tag{9}$$

where $u(\cdot)$ is the Heaviside unit step function. In addition, we can remove min() in Eq. (9) as follows

$$\begin{aligned} & Pr(T \leq t | I = j, D = \delta, X = x) \\ & = u\left(t - \frac{\delta - D_r}{V_f}\right), \\ & 0 \leq \delta \leq \min\left(\frac{(a - 2D_r + x)V_f + D_r V_b}{V_b + V_f}, a - 2D_r\right), \\ & = u\left(t - \frac{a - \delta - 2D_r + x}{V_b}\right), \\ & \quad \min\left(\frac{(a - 2D_r + x)V_f + D_r V_b}{V_b + V_f}, a\right) \leq \delta \leq a - 2D_r\Bigg). \end{aligned} \tag{10}$$

Finally, substituting Eq. (10) into Eq. (6), the closed form for the first term on the right side on Eq. (4) can be obtained as follows

$$
\begin{aligned}
&Pr(T \le t | I = 1) = \\
&\int_0^{\infty} f(\delta,x) \int_0^{m} u\left(t - \frac{\delta - D_r}{V_f}\right) e^{-\lambda_c P_c (a-\delta-2D_r+x)} d\delta \ dx \\
&+ \int_0^{\infty} f(\delta,x) \int_m^{a-2D_r} u\left(t - \frac{\delta - D_r}{V_f}\right) e^{-\lambda_c P_c (a-\delta-2D_r+x)} d\delta \ dx,
\end{aligned}
\tag{11}
$$

where $m = \min\left(\frac{(a-2D_r+x)V_f + D_r V_b}{V_b+V_f},\ a-2D_r\right)$.

On the other hand, we need to get a closed form for the second term on the right side of Eq. (4), where there are no replications for the packet in the opposite direction $I = 0$. In this case $I = 0$ and we can apply the same analysis as the $I = 1$ case except that the packet will be carried by its source vehicle until it reaches the next drone. Therefore, we can get the form for Eq. (9) for the case $I = 0$ as follows

$$
Pr(T \le t | I = 0, D = \delta, X = x) = u\left(t - \frac{\delta - D_r}{V_f}\right). \tag{12}
$$

In addition, the probability that the carrier vehicle leaves the highway over the distance $(\delta - D_r)$ is proposed in [3] as follows

$$
Pr(I = 1 | X = x, D = \delta) = 1 - e^{-\lambda_c P_c (a-\delta-2D_r+x)}. \tag{13}
$$

Therefore, the closed form for the second term on the right side of Eq. (4) can be obtained as follows $Pr(T \le t | I = 1) =$

$$
\int_0^{\infty} f(\delta,x) \int_0^{a-2D_r} u\left(t - \frac{\delta - D_r}{V_f}\right)(1 - e^{-\lambda_c P_c (a-\delta-2D_r+x)}) d\delta \ dx \tag{14}
$$

Using Eq. (4), Eq. (11), and Eq. (14), the closed form for the CDF of the vehicle-to-drone packet delivery delay can be simplified using MATLAB's Symbolic Computation toolbox with the resulting expression given in Eq. (15).

V. DRONES-ACTIVE SERVICE

There are many papers that uses a location service in the routing protocol for V2V communication as in [15]–[17]. The location service has the updated locations for vehicles such as HLS and GLS. Here, we propose a drones-active service (DAS). The DAS is a computational service that is added to the location service. By using the proposed mathematical framework, the service operator provides the number of drones needed to serve the VANET in the lowest vehicular density e.g., at the night period. However, DAS switches on some of these drones according to known vehicular density changes.

DAS detects the vehicular density of the highway after every specified time period. Then, based on the vehicle-to-drone delivery delay constraint and the detected vehicular density, DAS uses our proposed mathematical framework to obtain the maximum distance between two adjacent drones satisfying the delay constraint. After that, the DAS finds the required number of drones for the highway at that time. Finally, if the vehicular density increases, the DAS switches off some drones e.g., requiring their batteries to be recharged, and the other drones change their location based on the calculated distance between them. On the contrary, if the vehicular density decreases, the DAS switches on some drones again to reach the required number of drones for the highway at that time.

This method benefits from the mobile nature of the drones. The DAS approach takes into account the temporal vehicular density variation and helps to ensure the minimum number of active drones that can satisfy the required constraint on the vehicle-to-drone packet delivery delay. DAS can switch off some drones that need to recharge their batteries or based on any other configuration. Algorithm 1 explains the DAS in detail.

Algorithm 1 DAS

```
procedure START( )
    while ($true$) do
        detect $N_f$, $N_b$ from the location service
        $T_m \leftarrow T_{max}$
        $D_r \leftarrow Drone.range\,(Pathloss_{th}, altitude)$
        $drones_{on} \leftarrow$ count ($current\ active\ drones$)
        $drones_{off} \leftarrow$count ($current\ inactive\ drones$)
        $drones_{required} \leftarrow$Proposed.framework ($T_m, N_f, N_b, D_r$)
        if $drones_{req} > drones_{on}$ then
            switchon (difference ($drones_{req}$ , $drones_{on}$))
        else
            switchoff (difference ($drones_{req}$ , $drones_{on}$))
        end if
    end while
end procedure
```

VI. SIMULATION AND MODEL VALIDATION

This section compares our simulation results against those from our analysis. We implement our proposed protocol in NS-2 (v. 2.34). In addition, we use VanetMobiSim [18] to generate realistic vehicle mobilities and implement the mobility model mentioned in Section III. In this mobility model, a two-way highway segment is considered and there are vehicles over two lanes moving in opposite directions. Table 1 summarizes the configuration parameters used in the simulation.

Fig. 3 shows the analytical and simulation results for the CDF of the vehicle-to-drone packet delivery delay. The analytical results of the proposed model are plotted using Eq. (15). It can be seen that the two curves agree closely across all time values, indicating that our analysis is accurate in characterizing the vehicle-to-drone packet delivery delay. However, we can note that the simulation

$$Pr(T \leq t) = \int_{0}^{K_2} \frac{K_4 N \int_{0}^{K_3} K_1 K_5 \; d\delta}{a - 2D_r} \; dx + \int_{K_2}^{\infty} \frac{K_4 N \int_{0}^{a-2D_r} K_1 K_5 \; d\delta}{a - 2D_r} \; dx + \int_{0}^{\infty} \int_{0}^{a-2D_r} \frac{K_4 K_5 (1 - K_1) N}{a - 2D_r} \; d\delta \, dx$$

$$+ \int_{0}^{K_2} \frac{K_4 N \int_{K_3}^{a-2D_r} u\left(\frac{\delta - a + 2D_r - x + tV_b}{V_b}\right) K_1 \; d\delta}{a - 2D_r} \; dx, \text{ where } N = N_f + N_b, \; K_1 = e^{-\lambda P_c (a - \delta - 2D_r + x)}, \; K_2 = \frac{aV_b - 3D_r V_b}{V_f},$$

$$K_3 = \frac{V_f (a - 2D_r + x) + D_r V_b}{V_f + V_b}, \; K_4 = e^{-Nx}, \; K_5 = u\left(\frac{D_r - \delta + tV_f}{V_f}\right). \tag{15}$$

Table I
SIMULATION PARAMETERS

Simulation Parameter	Value
N_f (vehicles)	25
N_b (vehicles)	25
Drones density (drones/km)	0.2
Road segment a (km)	15
Simulation time (seconds)	600
Exit Probability P_c	0.2
Road junctions density λ_c	0.002
V_f (m/sec)	25
V_b (m/sec)	30
Simulation runs	130
Channel date rate (Mbps)	2
Drone altitude (m)	300

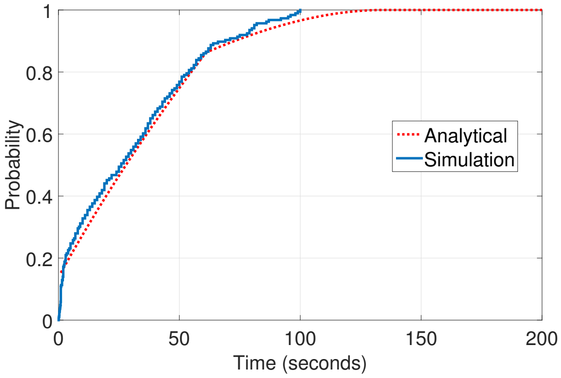

Fig. 3. Results for drone density 0.2 drones/km.

results have a small deviation from the analytical results. This is because our analysis focuses on the worst case where the original packet is stored by its source vehicle until it is within communication range of a drone. However, the source vehicle may forward the packets to a neighboring vehicle. As a result, the vehicle-to-drone packet delivery delay decreases.

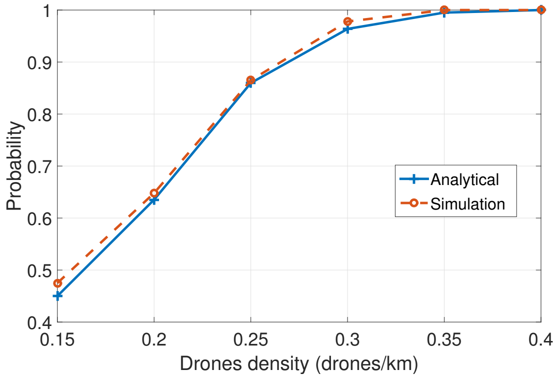

Fig. 4. CDF for T=40 seconds with different drone densities.

Fig. 4 shows the CDF of the vehicle-to-drone packet delivery delay for $T = 40$ seconds versus different drone densities using the same parameters as in Table I. It shows the effect of changing the drone density on the vehicle-to-drone packet delivery delay. The results show that the drone density highly impacts the CDF of the vehicle-to-drone packet delivery delay. With increasing drone density, the CDF of the vehicle-to-drone packet delivery delay increases for all values of the drone density. This is because increasing the drones density leads to decreasing a. As a result, the vehicle-to-drone packet delivery delay decreases.

VII. CONCLUSION

In this paper, we proposed a mathematical framework to determine the minimum drone density that stochastically limits the worst case for the vehicle-to-drone packet delivery delay. We focused on a two-way highway segment where vehicles over two lanes are moving in opposite directions. In addition, a vehicle acting as the packet source sends one replica of the packets in the opposite direction. Therefore, packets are carried either by their source vehicles or a carrier vehicle moving in the opposite direction. Moreover, we proposed DAS to obtain the required number of active drones satisfying the vehicle-to-drone packet delivery delay constraint after every specified time period. Simulation results show the accuracy of our mathematical framework and reflect the relation between the vehicle-to-drone packet delivery delay and the drones density. In our future work, we will consider infrastructure-less drones with V2V communication and include the queuing. In addition, we will formulate the problem as an optimization problem to achieve the minimum end-to-end delay for V2V communication with a minimum number of drones. Moreover, we will formulate an optimization problem to obtain the optimal placement for the drones in VANETs using DAS.

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