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Towards opportunistic UAV relaying for smart cities

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Abstract: With recent advances in cooperation among mobile computer systems, Unmanned Aerial Vehicles (UAVs) can be expected to be operated in large numbers and become a part of daily life for a variety of use cases. UAVs are already envisioned to act as mobile base stations, e.g., for situations with high node densities and strong communication requirements. However, UAVs are typically imagined to be provided specifically for this purpose. In this work, we study the effects of exploiting randomly passing UAVs at an urban intersection for the communication between vehicles on the ground. We show that a UAV, while following its primary mission, can support cooperative driving vehicles in a purely opportunistic fashion by collecting periodic wireless broadcasts from vehicles and propagating all collected information periodically in an aggregated format. Using simulations, we show that such an opportunistic UAV relaying approach can lead to an improvement of approx. 6 percentage points (% points) in terms of perception of other vehicles.

Keywords: UAV, vehicular network, wireless network, cooperative perception

1 Introduction

A current trend in the Internet of Things (IoT) and Smart Cities are Unmanned Aerial Vehicles (UAVs), or drones, that are considered for more and more use cases every day [LXW+20]. To give an example, in the last years, aerial vehicles were considered for parcel delivery services – and companies like DHL or UPS have already presented prototypes. Thus, a high volume of UAVs can be expected to be in the air in future smart cities.

A second trend is cooperative driving to improve today's traffic problems like congestion, environmental pollution, and safety. By enabling vehicles to communicate wirelessly with each other, decisions can be taken cooperatively, e.g., to avoid collisions at intersections. To make this possible, reliable communication between vehicles is a prerequisite. Communication is usually based on Radio Frequency (RF) technology such as IEEE 802.11p. However, especially in urban scenarios, buildings and other obstacles have a significant impact on radio propagation [HS19].

In this work, we assume that UAVs can also be used opportunistically, as relays for communicating vehicles. We show that randomly passing UAVs lead to an increased perception of other vehicles if these UAVs are used for opportunistic relaying and thus temporarily support communication between ground nodes. For this, we use an approach for UAVs that collects wireless broadcasts from vehicles and transmits an aggregated packet (containing information about its surrounding) to all reachable vehicles. We consider an urban intersection which is surrounded by buildings, making the exchange of information more complex and difficult. We show that this approach can lead to an improvement of approx. 6 percentage points (% points) in terms of perceived vehicles. However, this improvement is highly dependent on different variables such as altitude, speed, number of UAVs, and flight routes.

2 Related Work

In recent years, the research community published a high number of works on cooperation between vehicles and UAVs.

Weisen et al. [SZL+18] proposed a UAV assisted framework to connect UAVs with vehicular networks on the street. The framework supports different communication technologies like Dedicated Short Range Communication (DSRC) or LTE-based communication and was evaluated using a highway simulation. Dedicated UAVs were used to relay packets between multiple vehicles. They show that the average delay of the communication is decreased, while the throughput is increased when the proposed framework is used instead of traditional IEEE 802.11p based communication between vehicles only. However, the work requires a dedicated deployment of drones and is does not utilize existing UAV in the air.

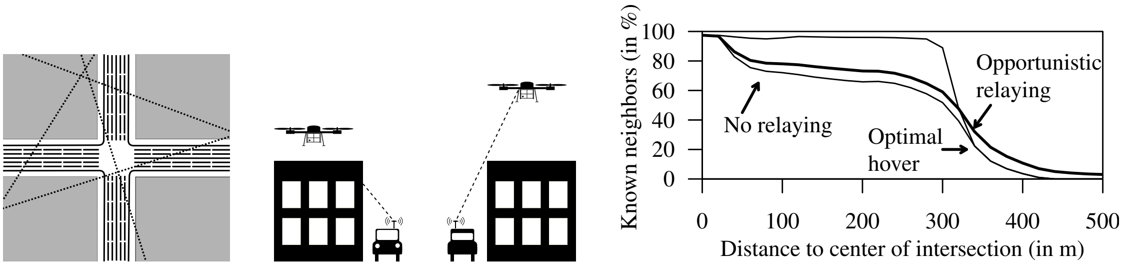
Mozaffarie et al. [MSB+19] provide a broad view of applications and challenges regarding UAVs for wireless networks. They also point out the use of drones to support vehicular networks as a promising use case.

Lui et at. [LXW+20] present different opportunistic transmission models and corresponding application scenarios for UAVs. Besides that, the authors show that the average data rate of a network can be increased for delay-tolerant users, but also the amount of collected data gathered by UAVs is increased. The description of the experiments, however, leaves questions unanswered, for example, regarding scenario and framework conditions. However, the work shows clear research directions for future work regarding the use of UAVs for opportunistic relaying.

In this paper, we investigate the impact of UAVs on vehicular networking applications utilizing detailed computer simulations with realistic communication and mobility patterns for passenger cars. In doing so, we give a detailed, if narrow first look on application performance, highlighting open issues, which should be investigated in future work.

3 Simulations

We investigate the impact of opportunistic UAV relaying on cooperative perception using computer simulations using the popular open-source vehicular network simulator Veins, coupling the OMNeT++ INET Framework for modeling wireless networking and SUMO for modeling road traffic mobility. We consider an intersection with four arms (500 m each) that is surrounded by buildings, sketched in Figure 1a. All buildings have a height of 20 m and a distance of approx. 10 m to the roads. We consider the free-space path loss model for radio propagation (no vehicle shadowing), but treat buildings as fully opaque to radio transmissions. To generate UAVs on random missions, we spawn UAVs following an exponential distribution with a mean of 30 s. Each follows a straight trajectory, created at a uniformly distributed random angle and crossing through a point that is generated randomly following a normal distribution centered on the inter-



(a) top view (b) side view (c) results

Figure 1: (a) Opportunistic relaying assumes random flight paths through the city. (b) Depending on the flight altitude, the UAV gets a different angle with respect to vehicles on the ground. With a greater altitude, the UAV is capable of receiving more information (though, of course, the greater distance causes greater path loss). (c) Results show the relative share of detected vehicles within an area of 100 m (euclidean distance) around the center of the intersection binned with 20 m. Confidence intervals are sufficiently small and not graphically shown. We see this distance as relevant for various applications, for example cooperative perception or intersection collision avoidance. The *optimal hover* approach shows the greatest advantage, but also randomly passing UAVs (*opportunistic relaying*) have an advantage of almost 6 % points with a distance of 100 m towards the intersection.

section and with a standard deviation of 100m. A single flyover thus takes approx. 120 s. UAVs are moving at a fixed altitude of 90 m and with a constant speed of 20 m/s. Our data shows that, because of building obstructions (illustrated in Figure 1b), increasing the altitude would lead to a better perception of vehicles on the road. Note, however, that, on the flip side, a UAV at higher altitude – i.e., a larger distance from the vehicle – suffers from higher free space path loss. We can thus note that many chosen values (e.g., high speed of UAVs, fully opaque buildings) can be considered worst case assumptions while others are worthy of further exploration.

Vehicles are spawning at a rate of 1 veh/s at the end of each arm of the intersection taking random trajectories through the intersection. They are transmitting wireless broadcasts (here: IEEE 802.11p beacons containing status information for cooperative awareness) at a frequency of 10 Hz. UAVs that overhear broadcasts from vehicles transmit aggregated information (all perceived vehicles) of all received broadcasts every 500 ms.

Received broadcasts are used by each vehicle to build a neighbor table of vehicles in their surroundings. We remove an entry from the neighbor table for which no transmission from a certain vehicle has been received for more than 1 s. We evaluate the impact of UAVs on the perception of vehicles by comparing three approaches:

1. *No relaying*: No UAVs are present in the scenario.
2. *Optimal hover*: A single UAV is present, hovering above the center of the intersection.
3. *Opportunistic relaying*: UAVs are following random missions.

We perform 50 independent runs for statistical confidence and collect data for 600 s after the transient phase at the beginning of each simulation ends.

To quantify perception in our scenario, we consider, for each vehicle, the fraction of perceived neighbors (entry in neighbor table) within an area of 100 m around the center of the intersection (i.e., those which might be relevant for realizing an intersection collision avoidance application).

Figure 1c shows the mean value of this metric depending on how far the observing vehicle is from the center of the intersection. The *optimal hover* scenario achieves the highest visibility of other vehicles at the intersection. Because of packet loss, not 100 % of all vehicles are perceived. The *opportunistic relaying* scenario shows a slight drop in the known vehicles after about 25 meters. This is the point where a vehicle left the center of the intersection and thus becomes surrounded by buildings. However, because of the sporadic flyover of a UAV, the number of known neighbors is still approx. 6 % points higher compared to the *no relaying* approach, which results in the lowest value for perceived neighbors.

4 Conclusion

We investigated the effects of opportunistic Unmanned Aerial Vehicle (UAV) relaying on a simple collective perception application for vehicles near an urban intersection. We have shown that the number of perceived vehicles can be increased by about 6 percentage points (% points) when UAVs are collecting wireless broadcasts from vehicles and propagating them periodically in an aggregated format without changing their primary mission. This improvement, however, highly depends on different factors like the altitude, speed, number of UAVs, and flight routes. These variables show the complexity of the opportunistic UAV relaying approach and leave ample room for future work.

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