UAV Trajectory Design for UAV-2-GV Communication in VANETs

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2021 IEEE ICOIN

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Date : **Jan 14,2021**

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Introduction

- Owing to the flexibility, automation and quick deployment features of unmanned aerial vehicles (UAVs), they can be used in vehicular area networks (VENETs).
- However, the heterogeneity, high mobility and network dynamics of VANETs pose significant challenges for such communication.
- In this paper, we propose a trajectory design scheme for efficient UAV-2-GV communication in VANETs.
- Given the high traffic routes of a dense city, the UAV trajectory is optimized to serve the maximum number of GVs.
- After the deployment of the UAVs according to the designed trajectory, optimal vehicle association and power allocation is performed.
- Simulation results reveal that the proposed UAV-assisted VANETs can deliver better rates as compared to the traditional terrestrial base-station (TBS)-based networks.

Contributions

- We formulate the problem to optimize the UAV trajectory, downlink power allocation, and vehicular association.
- To solve the formulated problem, we first compute the optimal UAV trajectory using the network flow approach where the UAVs follow the heavy traffic flow.
- We simplify the trajectory design scheme by reducing the number of decision points at the traffic intersections only instead of deciding the trajectory at the intermediate road locations.
- To solve the vehicular association, we select the best channel gain users under the capacity constraints of the UAVs. Then the power allocation is performed to deliver a fixed threshold of SNR.
- Simulation results reveal that the proposed scheme can significantly reduce the trajectory design computation complexity. It is also observed that the data rate delivered by the UAVs is significantly higher in comparison to the RSU-based network.

- We consider a vehicular network in a dense city with heavy traffic flows during peak hours.
- A set of flying rotary-wing UAVs denoted by $\mathcal{N} = \{1, 2, \ldots, N\}$ deployed to serve the set of vehicles denoted by $\mathcal{V} = \{1, 2, \ldots, V\}$
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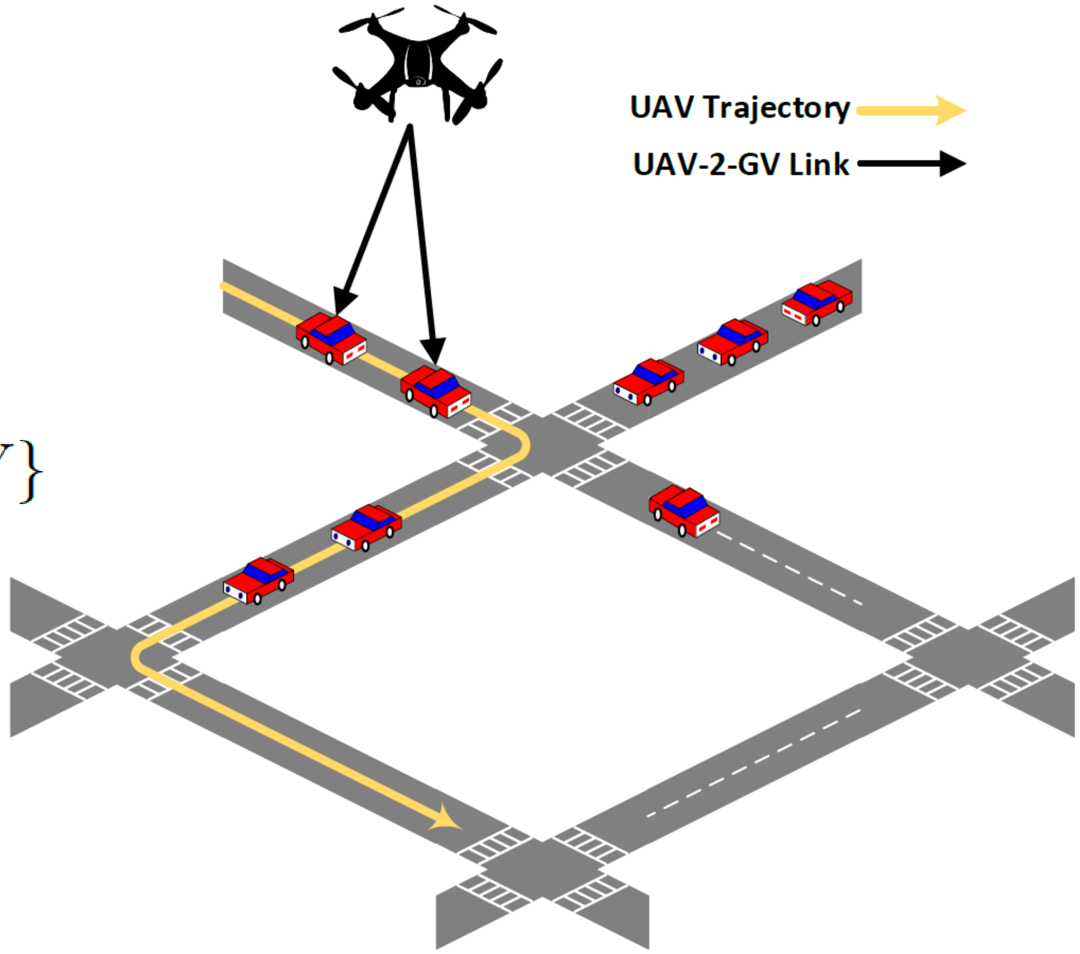


UAV-2-GV Communication Model

- Distance:

$$d_{nv} = \sqrt{\|x_n - x_v\|},$$

UAV location (x_n)

Vehicle location (x_v)

- Path-loss:

Los pathloss

$$\gamma_{\text{LoS}} = \eta_{\text{LoS}} \left(\frac{4\pi f_c d_{nv}}{c} \right)^{\alpha},$$

Non-Los pathloss

$$\gamma_{\text{N-LoS}} = \eta_{\text{N-LoS}} \left(\frac{4\pi f_c d_{nv}}{c} \right)^{\alpha},$$

Total pathloss

$$\gamma = P(\text{LoS})\gamma_{\text{LoS}} + P(\text{N-LoS})\gamma_{\text{N-LoS}}.$$

Probability of non-Los ($P(\text{N-LoS})$)

- Probability of LoS:

$$P(\text{LoS}) = \frac{1}{1 + a\,exp(-b(\frac{180}{\pi}\theta - a))},$$

Environmental constants (a, b)

- SINR:

$$\text{SNR}_{nv} = \frac{p_{nv} g_{nv}}{\sum_{n'} p_{n'v} g_{n'v} + N_0},$$

Power Allocation (p_{nv})

- Rate

Bandwidth (W)

$$R_{uv} = W \log\left(1 + \text{SNR}_{uv}\right),$$

- Optimization problem

$$\max_{\mathcal{T},\boldsymbol{p},\boldsymbol{a}} \sum_{n\in\mathcal{N}} \left(\sum_{v\in\mathcal{V}} a_{nv} R_{nv} \right), \quad (10)$$ **Network Utility**

$$\text{s.t.} \quad \text{SNR}_{nv} \geq \Gamma, \quad \forall n \in \mathcal{N}, v \in \mathcal{V}, \quad (10a)$$ **SINR threshold**

$$\sum_{v\in\mathcal{V}} p_{nv} \leq P_n, \quad \forall n \in \mathcal{N}, \quad (10b)$$ **Power budget**

$$0 \leq p_{un} \leq P_{\max}, \quad \forall n \in \mathcal{N}, v \in \mathcal{V}, \quad (10c)$$ **Power bounds**

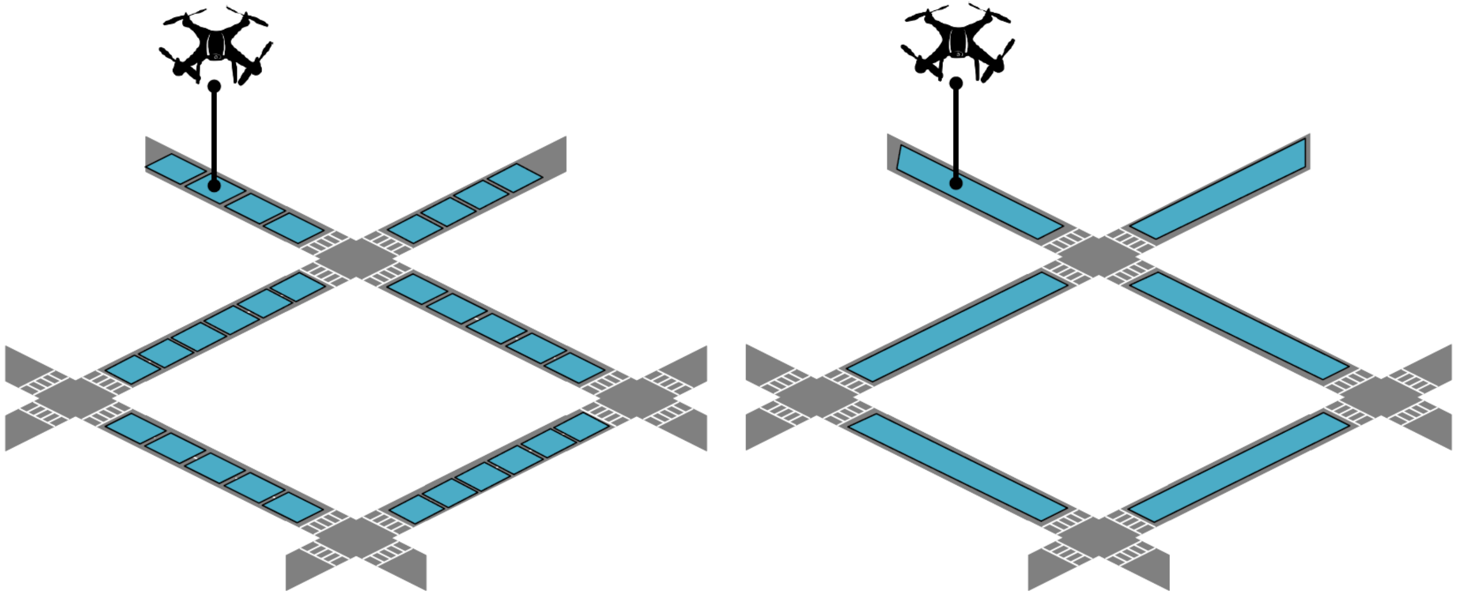
$$\sum_{v\in\mathcal{V}} a_{nv} \leq C_n, \quad \forall n \in \mathcal{N}, \quad (10d)$$ **Association capacity**

$$a_{nv} \in \{0,1\}, \quad \forall n \in \mathcal{N}, v \in \mathcal{V} \quad (10e)$$

$$\mathcal{T} \in \mathcal{L}, \quad \forall n \in \mathcal{N}, v \in \mathcal{V}, \quad (10f)$$

UAV Trajectory Design Scheme

- To start the trajectory, the UAV is deployed at the most dense location in the network containing the highest number of vehicles.
- This initial location is added in the trajectory as $\mathcal{T} = \{l_1\}$.
- The average speed $\bar{s_v}[l]$ of the vehicles is computed which gives the UAV speed $s_u[l]$.
- This process is continued to complete the trajectory $\mathcal{T} = \{l_1, l_2, \ldots, l_m\}$.



(a) Trajectory design approach for short road areas. (b) Trajectory design approach for long road areas.

- Given the trajectory and location of the UAV, the second sub-problem is the optimal vehicle association and power allocation

$$\max_{\boldsymbol{p}} \sum_{n\in\mathcal{N}} \left(\sum_{v\in\mathcal{V}} a_{un} R_{nv} \right), \tag{11}$$

$$\text{s.t.} \quad \text{SNR}_{nv} \geq \Gamma, \quad \forall n \in \mathcal{N}, v \in \mathcal{V}, \tag{11a}$$

$$\sum_{v\in\mathcal{V}} p_{nv} \leq P_n, \quad \forall n \in \mathcal{N}, \tag{11b}$$

$$0 \leq p_{un} \leq P_{\max}, \quad \forall n \in \mathcal{N}, v \in \mathcal{V}. \tag{11c}$$

- Vehicle Association:

Lemma 2. *To associate the optimal vehicles from V_l number of vehicles at location l, we construct the sorted set of vehicles denoted by V_l' according to the received SNR level SNR_{nv}. Next we select the first C_n number of vehicles to get optimal association a_{un}^* from this set V_l' which have $SNR_{nv} > \Gamma$ which is expressed in the form of indicator function as follows:*

$$a_{un}' = \mathbb{1}\{SNR_{nv} > \Gamma\}, \forall v \in V_l' \tag{13}$$

where $\mathbb{1}\{\cdot\}$ denotes the indicator function and it represents the vehicles from the sorted set V_l' which satisfy the SNR threshold constraint. Next optimal associated vehicles a_{un}^* are chosen by selecting first C_n vehicles from a_{un}'.

- Power Allocation

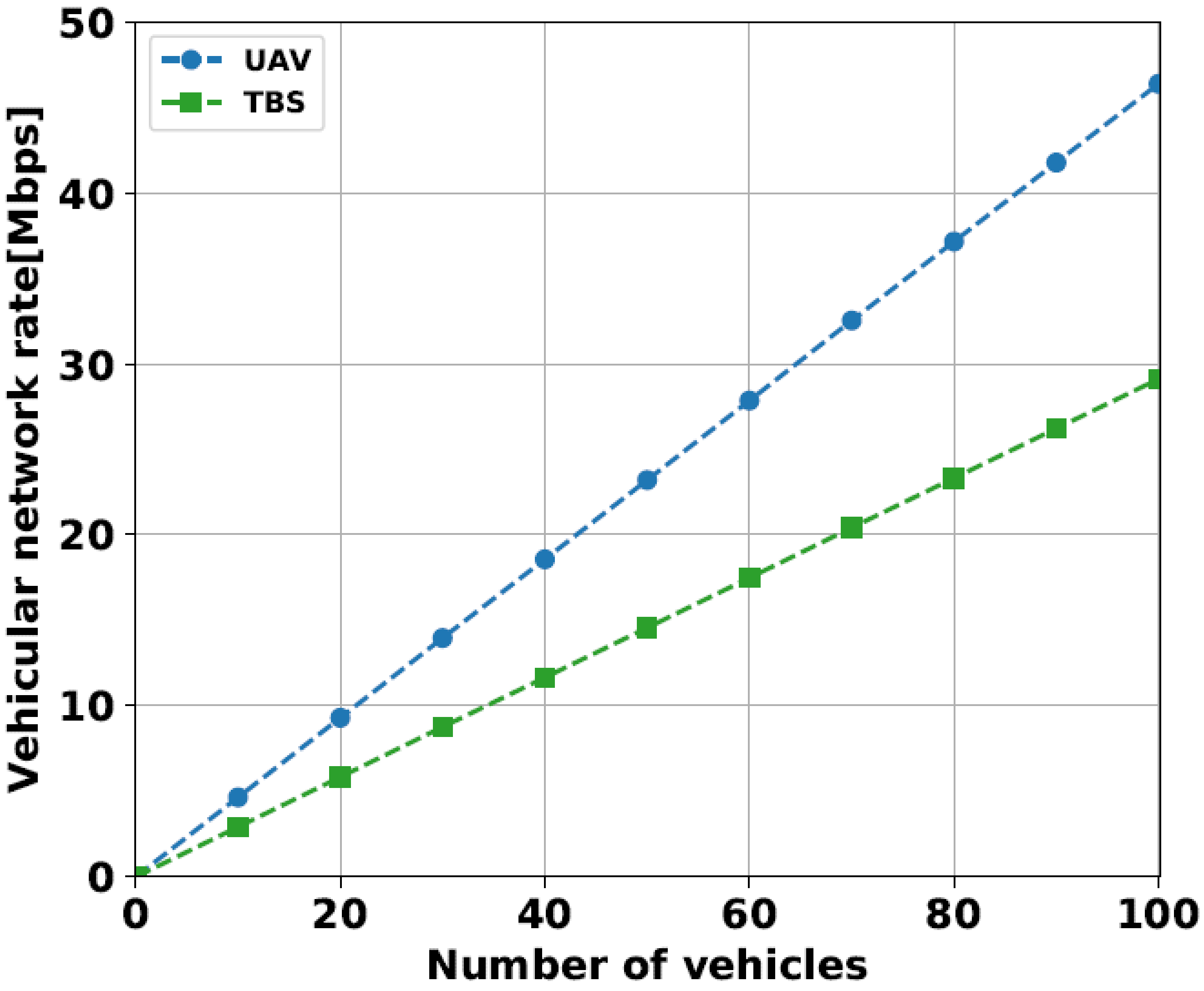
$$p_{un}^* = \min\left[\frac{\Gamma\left(\sum_{n'} p_{n'v} g_{n'v} + N_0\right)}{g_{nv}}, P_{\max}\right]$$

Algorithm

Algorithm 1 UAV trajectory design and resource allocation algorithm

Input: $\mathcal{V}$, x_v, and s_v.
Compute V_l and $s_u[l]$ at each location $l \in \mathcal{L}$.
The UAV is deployed at most dense location with the speed $s_u[l]$.
Channel gain between UAV and vehicles is computed using (2)-(7).
SNR is computed by fixing the $p_{un} = P_{\max}$.
Vehicle association is performed using Lemma 1 according to the indicator function in (13).
Optimal power allocation is computed from (14) for the associated vehicles a^*_{un}.
The UAV is moved to the next neighboring location which has the highest number of vehicles.
Output: $\mathcal{T}$, a^*_{un}, and p^*_{un}.

Simulation Results



Simulation Results

Conclusions

- In this paper, we have studied the UAV-based vehicular network to support the ground terrestrial network in peak traffic hours.
- We formulate the joint optimization problem for the trajectory design of UAV and resource allocation to the vehicular communication.
- In the future, we will extend this work to design the mobility model for the UAVs to reduce the huge message passing overhead for the instantaneous vehicular speed and location information.
- We will also design the framework for the interference management with the coexisting terrestrial network.

Thank You !!!