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Fog-Assisted Cooperative Protocol for Traffic Message Transmission in Vehicular Networks

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ABSTRACT Traffic information exchange between vehicles and city-wide traffic command center will enable various traffic management applications in future smart cities. These applications require a secure and reliable communication framework that ensures real-time data exchange. In this paper, we propose a Fog-Assisted Cooperative Protocol (FACP) that efficiently transmits uplink and downlink traffic messages with the help of fog Road Side Units (RSUs). FACP divides the road into clusters and computes cluster head vehicles to facilitate transmission between vehicles and traffic command center or fog RSUs. Using a combination of IEEE 802.11p and C-V2X wireless technologies, FACP minimizes the time required by a vehicle to retrieve traffic information. Furthermore, FACP also utilizes cooperative transmissions to improve the reliability of traffic messages. Simulations results show that FACP improves the reception rate and end-to-end delay of traffic messages.

INDEX TERMS Vehicular networks, traffic information, C-V2X, IEEE 802.11p.

I. INTRODUCTION

Vehicular communication has many potential applications including passenger safety, vehicle route guidance, emergency notification sharing, and on the road Internet access [1]–[3]. Future smart cities will use an intelligent road traffic management system to avoid traffic congestion and reduce travel time. This will allow significant savings in terms of fuel consumption and traveling time [4]–[7].

Two major wireless technologies that will be the part of future vehicular networks include IEEE 802.11p (based on Wi-Fi) and C-V2X (based on cellular communications) [8]–[10]. Many car manufacturers plan to launch smart and connected vehicles in the future that will include chipsets of these wireless technologies. While IEEE 802.11p provides ad hoc short-range communication between vehicles, C-V2X enables long-range infrastructure-based communication [11], [12]. Both these technologies are working on updated standards such as IEEE 802.11bd and 5G New Radio (NR) to improve data rate and network capacity [8], [13].

Traffic management applications require information exchange between vehicles and city traffic command center. Vehicles initiate traffic information query request and send to the traffic command centers using Road Side Units (RSUs). Traffic command centers work on the query and send the response (with updated traffic information) back to the vehicle. A secure and reliable data dissemination protocol is vital to these traffic management applications [14]–[16].

Reliable traffic information dissemination faces many challenges [17]. Since vehicles are far away from the traffic command centers and RSUs are not always within the transmission range of vehicles, either a multi-hop data dissemination technique using IEEE 802.11p is required or C-V2X can be used for long-range messages [18], [19]. Multi-hop data dissemination suffers from long delays and also requires fre-

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quent retransmissions at every hop. Relying solely on C-V2X may cause network congestion for regular cellular communication. Therefore, an integrated solution that takes into account the advantages of both IEEE 802.11p and C-V2X while not overloading any of these networks is required. Vehicle mobility is also a challenge because query vehicles move away from the location they initiated the query. Therefore, traffic command centers need the updated location of all the query vehicles to transmit the response messages.

Fog computing is a paradigm that enables computing of data closer to the edge with the help of fog nodes [20], [21]. It provides many advantages such as data analysis, storage resources, and network management closer to the user. Future networks will deploy fog nodes to save bandwidth and reduce network latency. In vehicular network, RSUs are ideal candidates to serve as fog nodes [22]–[25]. They can carry out data computations and provide data storage facilities. They can also assist in efficient network management [26]. Data dissemination protocols can use the network information of fog RSUs to route data, allocate resources, control transmission parameters, and manage cooperative transmissions [27]. Moreover, fog RSUs can interact with the traffic command center, cache important traffic information in its data storage and provide quicker traffic notification to the vehicles.

In this paper, we propose a Fog-Assisted Cooperative Protocol (FACP) that enable vehicles to efficiently transmit traffic information. FACP segments road into clusters and select cluster head vehicles with the assistance of fog RSUs. Cluster head vehicles collect query messages on behalf of the cluster using IEEE 802.11p and transmit it to the fog RSU through C-V2X. Similarly, the fog RSU transmits the response messages of the whole cluster to the cluster head vehicle, which then sends it to the individual query vehicles. FACP also introduces a mechanism to enhance the reliability of response messages through cooperative transmissions. Simulation results verify the benefits of FACP in terms of reception rate and end-to-end delay of traffic messages.

The paper is organized as follows. Section II provides an overview of the related work in the literature. Section III presents the system model and Section IV explains the working of FACP. Performance evaluation is presented in Section V. Finally, conclusions are drawn in Section VI.

II. RELATED WORKS

In this section, we present a brief survey of the literature related to clustering, multi-hop communications, C-V2X communications and cooperative communications in vehicular networks.

Clustering is a useful technique in vehicular networks as it allows a group of nearby vehicles to communicate efficiently. As the data delivery process in a vehicular network is a challenging task due to varying vehicle speed and position, clustering also helps in efficient time or frequency resource allocation. In this regard, a cluster-based cooperative caching approach with mobility prediction is proposed for Vehicular named data networking (VNDN) in [28]. A clustering algorithm using the predicted location of vehicles is developed to group vehicles with similar mobility patterns. However, cluster heads are frequently changed due to varying vehicle speeds of the vehicles. Reference [29] proposed a Passive Multi-hop Clustering (PMC) algorithm that uses a node degree to evaluate the stability of the nodes within a cluster. To improve the stability of the cluster, the node with the highest stability is selected as the cluster head. In another study in [30], enhancement in the uplink data rate is achieved using a self-adaptive clustering algorithm that can be deployed in a heterogeneous vehicular network environment based on IEEE 802.11p and C-V2X. The proposed algorithm optimally evaluates the cluster size based on mobility information. Moreover, bandwidth allocation for both IEEE 802.11p and C-V2X radios is also optimized by considering the load in each cluster.

Related to multi-hop communications, [31] proposed a multi-hop broadcast protocol that uses a parameter called node index (defined as the relative distance of each node from the source) to assign forwarding probability to the vehicles. Furthermore, the probability of collisions is further reduced by using clustering and only selecting cluster heads for multi-hop transmissions. Reference [32] proposed a multi-hop algorithm for a Massive Input Massive Output (MIMO) system that maximizes the Signal to Noise Ratio (SNR) to determine the best path between the source and the destination.

A geo-based scheduling algorithm for C-V2X is proposed in [33] where vehicles autonomously allocate resources based on neighbor mobility information for better channel coordination. The proposed algorithm overcomes the hidden node problem in the Semi-Persistent Scheduling (SPS) based medium access protocol for C-V2X. The work in [34] uses cellular eNodeBs to allocate V2V resources. The proposed algorithm considers factors such as SNR and network latency to find the optimal V2V links for data transmission. Reference [35] evaluates the performance of C-V2X for road hazard warning applications. An analytical model is developed and metrics such as latency and packet loss probability are presented for mode 3 and mode 4 of C-V2X.

To increase the reliability and throughput of the vehicular network, [36] proposed a cooperative medium access protocol that improves the slot utilization of vehicles. By effectively coordinating unreserved time slots for cooperative transmissions, the proposed protocol reduces cooperation collisions and better utilize the cooperation opportunities. In [37], a stochastic model is developed to evaluate the reliability of data transmission in a vehicular channel. Moreover, vehicular computation tasks have been divided into smaller sub-tasks that are executed by many cooperative computing nodes in parallel. An optimal processor scheduling algorithm is thus presented to reduce the application execution time. The work in [38] proposed a clustering algorithm based on the k-means algorithm. An optimal power allocation scheme is also proposed that reduces the power consumption of cluster head vehicles.

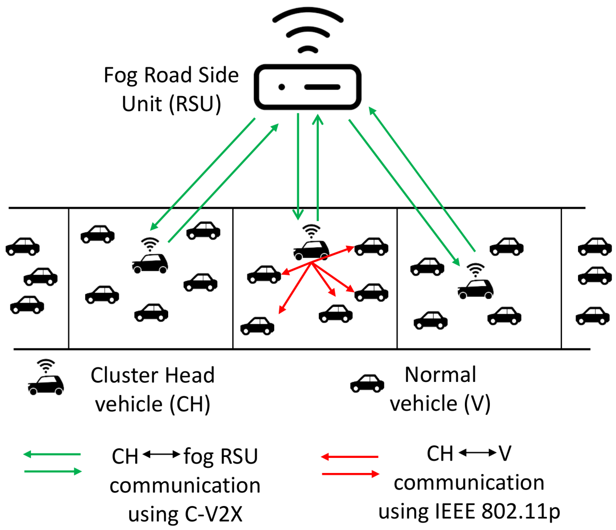

FIGURE 1. Cluster-based traffic message transmission using IEEE 802.11p and C-V2X.

III. SYSTEM MODEL

We consider a vehicular networking scenario as shown in Fig. 1 where vehicles on the road are equipped with both IEEE 802.11p and C-V2X transceivers. Vehicles share traffic messages with the fog RSUs using a combination of IEEE 802.11p and C-V2X technologies. Traffic messages are of two types namely query and response. Initially, a vehicle sends traffic information query to the fog RSU. After the query is processed, fog RSU sends back the traffic information response message back to the vehicle. Generally, response messages are much larger as they contain detailed traffic information.

We divide the road into clusters and a cluster head vehicle V_{ch} is selected for each cluster to establish efficient traffic message transmission between vehicles and the fog RSU. Cluster head vehicle serves three purposes, firstly collecting traffic query request from the vehicles in the cluster, secondly communicating with the fog RSU (on both uplink and downlink) on behalf of the cluster, and thirdly cooperative transmission of traffic response messages to the query vehicles (vehicle that sends the traffic request message).

The rationale behind using a cluster-based scenario in this paper is because it simplifies the transmission of traffic messages. A big challenge in traffic messages is that the query vehicle moves to a new position when the traffic response message is ready. As a result, it is hard for the fog RSU to locate the request vehicle and requires multi-hop transmission. By using cluster-based transmission, fog RSUs only need to interact with the cluster head vehicles to retrieve the updated location of the request vehicle. Another advantage of cluster-based transmission is that C-V2X transmission is needed by the cluster head vehicles only, thus reducing vehicular traffic load on the cellular network. Therefore, we find cluster-based transmission as a suitable choice for traffic message transmission.

IV. FOG-ASSISTED COOPERATIVE PROTOCOL FOR TRAFFIC MESSAGE TRANSMISSION

In this section, we explain the working of the proposed Fog-assisted Cooperative Protocol (FACP) for traffic message dissemination in vehicular networks. The key idea of FACP is to select cluster-head vehicles that can transmit traffic messages between vehicles and fog RSUs. In this paper, we have used fog RSUs to assist the vehicles in resource allocation and efficient dissemination of traffic information messages. In particular, the fog RSU assists the vehicles in cluster head selection based on channel information broadcast. Moreover, fog RSU also takes part in the cooperative transmissions phase by selecting cooperative relay vehicles and broadcasting cooperative transmission map.

FACP has four major components namely cluster head selection, query message transmission, response message transmission, and cooperative transmissions. Fig. 2 provides a summary of FACP. The timing diagram of FACP is shown in Fig. 3. It divides the time into four time slots. In the channel information broadcast time slot T_{cib}, vehicles share their channel conditions with each other. The query time slot T_q and response time slot T_r are used for query and response message transmissions respectively. Finally, cooperative time slot T_{coop} is used to transmit the response messages using cooperative relays.

A. CLUSTER HEAD SELECTION

FACP divides the road into fixed-sized clusters. The goal of cluster head selection is to find a suitable cluster head in each cluster that can disseminate query and response messages on behalf of the cluster. CH selection is performed by the fog RSU based on channel conditions. It works on the following three phases.

1) CHANNEL INFORMATION BROADCAST

In this phase, vehicles share their IEEE 802.11p and C-V2X channel information with the fog RSU. Vehicles share short channel information broadcast messages using the service channel of IEEE 802.11p (employing CSMA/CA protocol) within a fixed time slot T_{cib} as shown in Fig. 3. Channel information broadcast aims to make each vehicle aware of its channel conditions with all other vehicles in the cluster. Based on the channel information broadcast message, each vehicle maintains a table of neighboring vehicles with their location information and received Signal to Noise Ratio (SNR). Each vehicle computes average received SNR from its neighbor table and sends this information to the fog RSU as a measure of its IEEE 802.11p channel quality. Based on this information, fog RSU gets to know that if a particular vehicle is to be selected as a CH, it can disseminate the response messages to other vehicles with that value of average SNR. Moreover, each vehicle also computes its list of top tier vehicles. This list contains all the neighborhood vehicles from the neighbor table whose SNR is greater than a predefined threshold SNR_{th}. The list of top tier vehicles is shared with the fog RSU

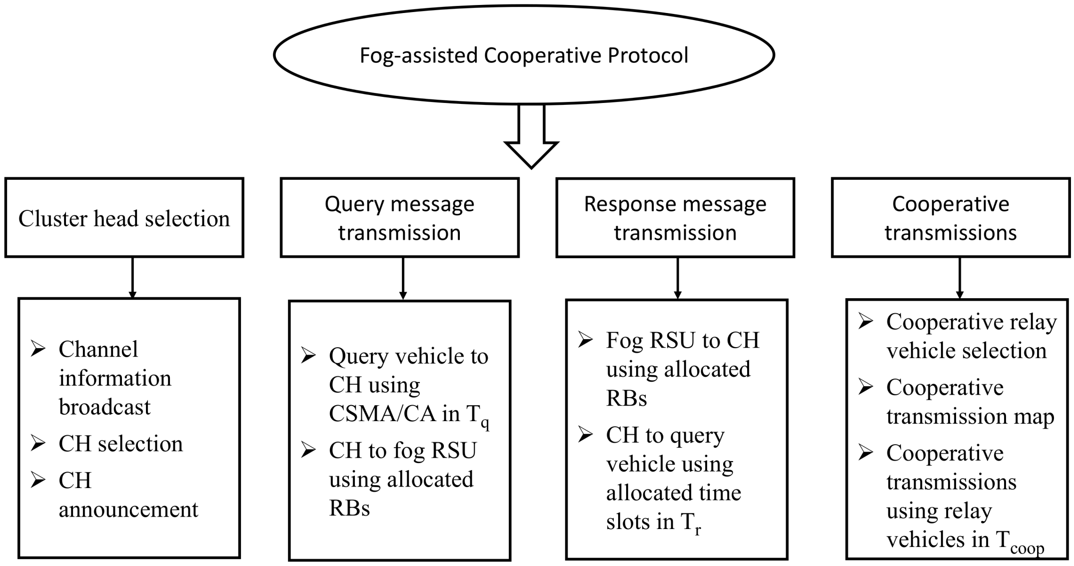

FIGURE 2. Summary of Fog-Assisted Cooperative Protocol.

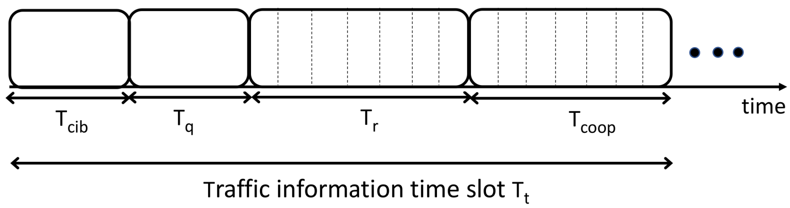

FIGURE 3. Timing diagram of query, response and cooperative messages shared over IEEE 802.11p channel.

Average SNR to neighbor vehicles	List of top tier vehicles	Average distance of neighbor vehicles	SNR of the pilot signal received from the fog RSU

FIGURE 4. Format of channel information broadcast message using C-V2X.

and used in finding cooperative vehicles in the cooperative transmissions component of FACP.

Base stations (fog RSUs) periodically send pilot signals to the vehicles as per the C-V2X standard. Vehicles compute the SNR of these pilot signals and share them back with the RSUs as channel information broadcast message. Therefore, as shown in Fig. 4, each vehicle shares four types of information with the fog RSU in the channel information broadcast phase, i) average SNR to neighbor vehicles from its neighbor table (based on IEEE 802.11p channel), ii) list of top tier vehicles, iii) average distance of neighbor vehicles from its neighbor table, iv) SNR of the pilot signal received from the fog RSU (based on C-V2X channel). This information is shared by vehicles on the C-V2X channel after every traffic information time duration T_t.

2) CH SELECTION

Cluster head is selected every T_t time interval by the RSU. Based on information received in the channel information broadcast phase, fog RSU selects the cluster head vehicle in this phase. Cluster head vehicle V_{ch} is selected as the one that can quickly transmit the response message to the query vehicle V_q. This is done by computing the response time for all potential cluster head vehicles c in V_{cell} as follows:

$$T_{resp}(r, c, q) = T_{r2c} + T_{c2q} \tag{1}$$

where T_{r2c} is the transmission time required for the response message to reach cluster head vehicle V_{ch} from the fog RSU. T_{c2q} is the average transmission time required for response message to reach each of the vehicle V_q from V_{ch}. T_{r2c} and T_{c2q} are given as follows:

$$T_{r2c} = \frac{L}{B_{V2X} \times \log_2(1 + \frac{P_r d_{rc}^{-\alpha_{rc}} h_{rc}}{N_0})} \tag{2}$$

and

$$T_{c2q} = \frac{L}{B_{802.11p} \times \log_2(1 + \frac{P_c d_{cq}^{-\alpha_{cq}} h_{cq}}{N_0})} \tag{3}$$

Algorithm 1 Cluster Head Selection Algorithm

for *every time interval* T_t **do**
  for *all potential cluster head vehicles c in* V_{cell} **do**
    Find fog RSU to cluster head vehicle response message transmission as $T_{r2c} = \frac{L}{B_{V2X} \times \log_2(1+\frac{P_r d_{rc}^{-\alpha rc} h_{rc}}{N_0})}$
    Find average cluster head vehicle to query vehicle response message transmission time as $T_{c2q} = \frac{L}{B_{802.11p} \times \log_2(1+\frac{P_c d_{cq}^{-\alpha cq} h_{cq}}{N_0})}$
    Find total response message transmission time as $T_{resp}(r, c, q) = T_{r2c} + T_{c2q}$
    Select cluster head vehicle which has the minimum total response message transmission time $V_{ch} \leftarrow \min_{\forall c \in V_{cell}} T_{resp}(r, c, q)$
  end
end

Here L is the size of response message in bits, B_{V2X} and $B_{802.11p}$ are the bandwidth of a C-V2X resource block and IEEE 802.11p channel in Hz respectively, P_r and P_c are the transmission powers of RSU and V_{ch} respectively, d_{rc} and d_{cq} represent the distances between the RSU and V_{ch} and between V_{ch} and V_q respectively, h_{rc} and h_{cq} are the small-scale fading channel coefficient of C-V2X and IEEE 802.11p channels respectively, and N_0 represents the noise power in dBm.

Cluster head vehicle is selected as the one that minimizes equation 1.

$$V_{ch} \leftarrow \min_{\forall v \in V_{cell}} T_{resp}(r, c, q) \tag{4}$$

3) CH ANNOUNCEMENT

Once a cluster head is selected for each cluster, fog RSU broadcasts its vehicle identification (ID) to all members of the cluster. The cluster head does not change until the time duration of T_t. After T_t, new channel information is obtained and fog RSU repeats the process of cluster head selection and announcement.

B. QUERY MESSAGE TRANSMISSION

Query messages are transmitted from vehicles to fog RSU using the following two phases

1) QUERY VEHICLE TO CLUSTER HEAD VEHICLE

In this phase, vehicles use the IEEE 802.11p and CSMA/CA protocol to transmit the query messages to the cluster head vehicle. Since query messages are small in size, the transmission time of these messages is short and CSMA/CA works well for these messages. For query messages, a fixed-sized time slot T_q is allocated as shown in the timing diagram Fig. 3.

2) CLUSTER HEAD VEHICLE TO FOG RSU

In this phase, cluster head vehicles of each cluster transmit the query messages to the fog RSUs using C-V2X. Messages are transmitted one by one using available resource blocks as per the scheduling algorithm of the cellular network.

C. RESPONSE MESSAGE TRANSMISSION

Response messages are transmitted from the fog RSUs to the query vehicles. The following two phases are used to transmit these messages.

1) FOG RSU TO CLUSTER HEAD VEHICLE

Once the query is processed, fog RSU prepares a response message and stores it in its queue. Based on last received channel information broadcast, fog RSU finds the current cluster of the query vehicle (as query vehicle may have moved away when it sent the query message). Upon availability of the next available resource block as per the scheduling algorithm, this message is transmitted to the cluster head vehicle using C-V2X.

2) CLUSTER HEAD VEHICLE TO QUERY VEHICLE

Cluster head vehicles transmit response messages to the query vehicles using time interval T_r as shown in Fig. 3. The time interval T_r is divided into time slots and within each time slot, a single response message is transmitted. The duration of T_r is variable depending on the number of response messages in the queue of cluster head vehicle.

D. COOPERATIVE TRANSMISSIONS

Cooperative transmissions improve the reliability of the response messages by using cooperative vehicles that serve as relays. Cooperative transmissions take place for all those query vehicles that are not within the top tier list of the cluster head vehicle. Therefore, the cluster head vehicle keeps the response messages destined to all those query vehicles in a cooperative queue and retransmit these messages using cooperative relay vehicles.

1) COOPERATIVE RELAY VEHICLE SELECTION

Fog RSU selects the cooperative relay vehicles since it has a top tier list of all the vehicles in the cluster (from channel information broadcast messages). A cooperative vehicle for a given response message is selected as the one which belongs to the top tier list of both the cluster head vehicle and the query vehicle. This means that the selected cooperative vehicle has good channel conditions with both source (cluster head vehicle) and the destination node (query vehicle). If there is more than one potential cooperative relay vehicle (that belongs to the top tier list of source and destination), one of them is randomly picked. If there are no potential cooperative relay vehicles, then one of the vehicles in the cluster is randomly selected to perform relaying job.

2) COOPERATIVE TRANSMISSION MAP

Fog RSU broadcasts a cooperative transmission map as shown in Fig. 5 to all vehicles in the cluster. This map notifies the selected cooperative relay vehicles about the retransmission of response messages. All vehicles that find their name

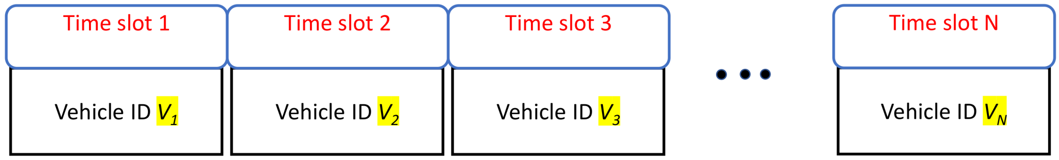

FIGURE 5. **Format of cooperative transmission map.**

in the cooperative transmission map note the slot number assigned to them for cooperative relaying. Moreover, this also informs the vehicles about the ending time of T_{coop} and the start of the next query time T_q.

3) COOPERATIVE TRANSMISSION USING RELAY VEHICLES

Finally, each selected relay vehicle retransmits the last received response message to the query vehicles in the allocated cooperative time slot.

V. PERFORMANCE EVALUATION

A. SIMULATION SCENARIO

We present the simulation scenario and parameters in Table 1. Using the Simulation of Urban MObility (SUMO) traffic simulator, we generate a traffic scenario of 3 km road length and 6 lanes. Vehicle density varies from 50 vehicles/km to 300 vehicles/km. Vehicle speeds range from $15 - 30$ m/s. We use MATLAB to implement the proposed FACP. The query packet size, response packet size, and channel information broadcast packet size is taken as 30 bytes, 1000 bytes and 10 bytes respectively. Packet generation rate is taken as $2 - 5$ packets/s.

We use a fixed query transmission time T_q and channel information broadcast time T_{cib} of 10 ms each. Cluster head size is set to 500 meter and SNR_{th} to find top tier vehicles in FACP is 20 dB. The query processing time at fog RSU is 10 ms. and a bandwidth of 10MHz per resource block. For IEEE 802.11p, the transmission range is set to 500m whereas the data rate and bandwidth used is 6 Mbps and 10 MHz. For C-V2X, we use a transmission range of 1000 meter and a bandwidth of 10MHz per resource block. The scheduling algorithm for C-V2X used is Maximum Throughput Scheduling (MTS). We also simulate cellular traffic on the C-V2X channel with each vehicle generating a packet size of 300 bytes at a packet generation rate of 2 packets/s.

We compare FACP with two following protocols

- **Multi-hop IEEE 802.11p** which uses a probabilistic multi-hop protocol based on IEEE 802.11p to transmit traffic messages
- **MTS C-V2X** which uses C-V2X transmissions with MTS algorithm to transmit safety messages.

We use the following two performance metrics

- **Packet Reception Ratio:** It is defined as the number of packets that are successfully received divided by the number of packets that were transmitted.
- **End-to-End Delay:** It is defined as the difference between the time when the response message is received by the query vehicle to the time when the query message was initiated.

TABLE 1. **Simulation parameters.**

Parameter		Value
Traffic	Road length	3km
	Number of lanes	6 (3 per direction)
	Vehicle density	$50 - 300$ vehicles/km
	Vehicle speed	$15 - 30$ m/s
Traffic Information Message	Query packet size	30 bytes
	Response packet size	1000 bytes
	Channel information broadcast packet size	10 bytes
	Generation interval	$2 - 5$ packets/s
FACP Parameters	Query transmission time, T_q	10 ms
	Channel information broadcast time T_{cib}	10 ms
	Cluster head size	500 meter
	SNR threshold SNR_{th}	20 dB
	Query processing time	10 ms
IEEE 802.11p Parameters	Transmission range	500 meter
	Data rate	6 Mbps
	$B_{802.11p}$	10 MHz
C-V2X Parameters	Transmission range	1000 meter
	Scheduling algorithm	Maximum throughput
	Cellular traffic packet size	300 bytes
	Cellular traffic generation rate	2 packets/s
	B_{V2X}	10 MHz
Propagation model	Pathloss	Dual-slope
	Fading	Nakagami $m = 1, 3$

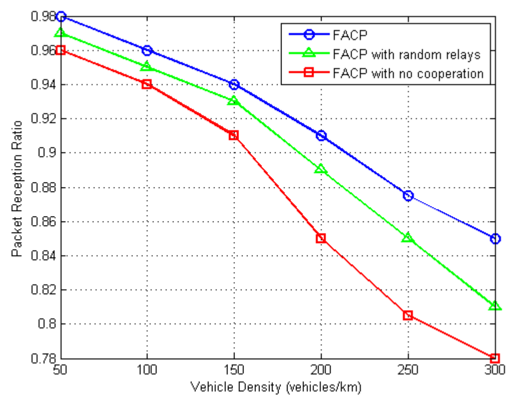

FIGURE 6. **Packet reception ratio for FACP with cooperative relays, random relays and without cooperation.**

B. RESULTS

We present packet reception ratio for FACP in Fig. 6 at different vehicle densities and compare it with the case when random relay nodes are selected for cooperation and when no cooperation is used. It can be seen that FACP transmits traffic information messages with a packet reception ratio of higher than 0.85 at the highest vehicle density of 300 vehicles/km. In comparison, using random relay vehicles results in a $0.01 - 0.06$ lower packet reception ratio. In case, cooperation is not used, the packet reception ratio falls up to 8% lower than FACP at the highest vehicle density. The gain

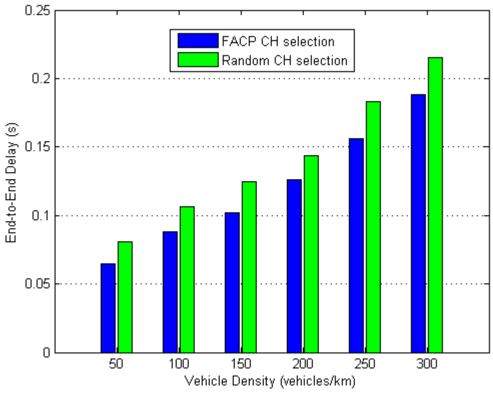

FIGURE 7. End-to-End Delay for FACP with proposed cluster head selection and with random cluster head selection.

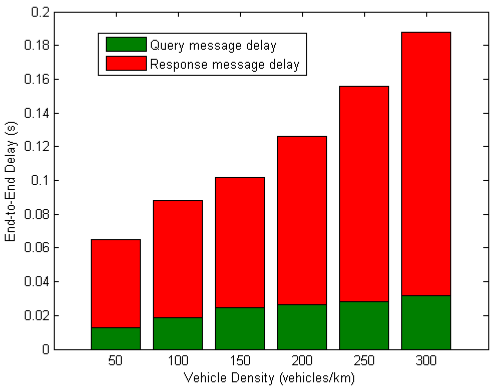

FIGURE 8. Query and Response delay for FACP at different vehicle densities.

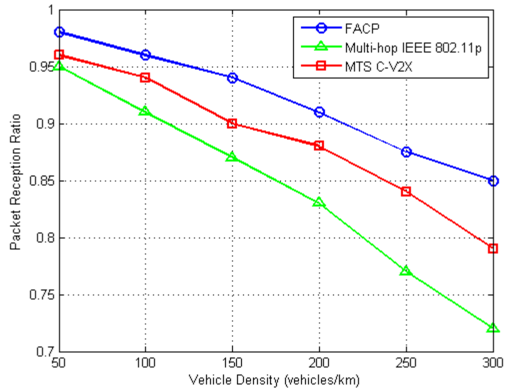

FIGURE 9. Packet reception ratio at different vehicle densities.

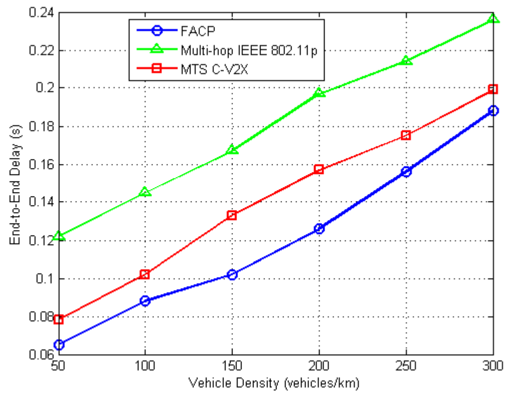

FIGURE 10. End-to-end delay at different vehicle densities.

in FACP is due to considering cooperative relays that have good channel conditions with the cluster head vehicle as well as the query vehicle.

We evaluate the performance of the cluster head selection algorithm in Fig. 7 in terms of end-to-end delay. Random cluster head selection incurs $16 - 27$ ms more delay than the FACP cluster head selection technique. In particular, at a vehicle density of 300 vehicles/km, random cluster head selection requires 215 ms to receive the response message whereas FACP cluster head selection needs 188 ms. This is because FACP selects a cluster head vehicle that minimizes the transmission time of response messages.

We show the query and response message delay for FACP at different vehicle densities in Fig. 8. Results show that response delay is more than 80% of the total traffic information delay (sum of query and response message delays). This is due to the larger packet size of the response message as well as the time required in the processing of the query. At a vehicle density of 300 vehicles/km, query message delay is 37 ms whereas the response message delay is 151 ms.

We compare the results of the packet reception ratio in FACP with the two other protocols in Fig. 9. It can be seen that FACP shows superior performance in terms of packet reception ratio as compared to both multi-hop IEEE 802.11p protocol and MTS C-V2X. While FACP delivers all packets with a reception ratio of higher than 0.85, this ratio falls to 0.79 and 0.72 for MTS C-V2X and multi-hop IEEE 802.11p protocols. The significant performance enhancement in terms of packet reception in FACP is due to efficient cluster head selection, transmission protocol design, and cooperative relay algorithm. MTS C-V2X shows superior performance as compared to multi-hop IEEE 802.11p. The reason is that multi-hop IEEE 802.11p transmits packets over multiple communication links to reach the destination and chances of failure are more as compared to single-hop communications in MTS C-V2X.

We present the end-to-end delay of FACP and the two other protocols in Fig. 10. FACP delivers response messages back to the query vehicle in less than 190ms at the highest vehicle density. In comparison, MTS C-V2X and multi-hop IEEE 802.11p require 12ms and 50ms more time to deliver response messages respectively.

We evaluate the effect of higher packet generation rate and higher Nakagmi m values on all the three protocols in comparison. At the highest packet generation rate of 5 packets/s and Nakagami m of 1, FACP shows 64 ms and 126 ms lower end-to-delay as compared to MTS C-V2X and multi-hop IEEE 802.11p protocols respectively. As we increase fading intensity and packet generation rate, end-to-end delay for FACP increases by 336ms at the highest vehicle density. FACP shows improved performance at higher transmission rate and

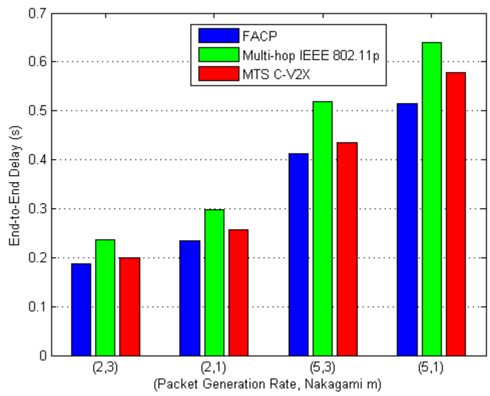

FIGURE 11. End-to-end delay at different packet generation rate and Nakagami *m* fading values.

poor channel conditions as compared to other protocols due to cooperative relays and using a combination of IEEE 802.11p and C-V2X to deliver traffic information messages.

VI. CONCLUSION AND FUTURE WORK

In this paper, we propose a Fog-Assisted Cooperative Protocol (FACP) for efficient traffic message transmissions using a combination of IEEE 802.11p and C-V2X technologies. By dividing the road into clusters and selecting cluster head vehicles with the help of fog RSUs, FACP transmits the query and response traffic information messages between vehicles and traffic command center. To improve the reliability of response messages, FACP also uses cooperative transmissions. Simulation results show that FACP improves the reception rate and end-to-end delay of traffic messages. In the future, we will explore the impact of cluster parameters on the communication delay and intelligent local computation of data at the RSUs.

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