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PROACTIVE MULTI-COPY ROUTING PROTOCOL FOR URBAN VEHICULAR AD HOC NETWORK

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ABSTRACT

A vehicular network topology is very dynamic compared to traditional mobile ad hoc network because of the movement and speed of the vehicles. Thus, a vehicular network is always partitioned due to this reason, especially if the vehicle density is low. In this situation where a direct end-to-end path between source and destination can be considered as non-existent, a regular ad hoc routing protocol with complete path discovery mechanism is not feasible since the routing path is usually disconnected due to the intermittent nature of network links. To overcome this problem, vehicles can be used as carriers to deliver messages using store-and-carry forwarding whenever forwarding option via wireless transmission is not available. It has been ascertained by the majority of researches in VANET that the carry and forward procedure can significantly affect an end-to-end delivery delay. This paper focuses on developing a proactive multi-copy routing protocol with carry and forward mechanism that is able to deliver packets from a source vehicle to a destination vehicle at a small delivery delay. The paper emphases on replicating data packets and distribute them to different relays. The proposed protocol creates enough diversity to reach the destination vehicle with a small end-to-end delivery delay while keeping low routing overhead by routing multiple copies independently. The simulation results in an urban grid model show that the proposed multi-copy forwarding protocol is able to deliver packets at small delivery delay compared to a single-copy forwarding algorithm without having to rely on real time traffic data or flooding mechanism.

Keywords: routing protocol, carry and forward, vehicular, vanet.

INTRODUCTION

In general, a vehicular ad hoc network (VANET) is formed between nodes an as-needed basis. To create a VANET, vehicles need to have wireless transceivers and computerized modules that enable the vehicles to act as network nodes. Similar to mobile ad hoc networks (MANET), VANETs consist of radio-enabled vehicles which act as mobile nodes and routers for other nodes. Although VANETs share a few common MANETs characteristics such as self-organization and self-management, short radio transmission range and limited bandwidth, they also have significant features that differentiate them from other types of ad hoc networks [1], [2].

In VANETs, the vehicles mobility and network topology are highly diverse especially in an urban area. Multi-hop forwarding through a large geographic area is usually expected for disseminating data to a faraway vehicle [3]. Due to VANET's dynamic nature, it is common for the forwarding path to go over some areas of the network where the number of vehicles is low and a next forwarding vehicle is hard to find. In this situation, an end-to-end connection over a large distance may not always exist. To support data dissemination in the presence of partitioned or disconnected networks, a carry and forward approach is used where a forwarding vehicles carries the data packet when a suitable next hop vehicle is not available, and forward the packet when a new vehicle moves into its vicinity. Basically, packets are stored and carried temporarily in a moving vehicle while waiting for opportunities to forward them via wireless channel. Although this approach can increase the chance of

delivering the data packet to its destination, it can influence the packet's end-to-end delivery delay since the packet is moving with the speed of the carrying vehicle as opposed to the speed of light. Majority of VANET routing protocols is now designed to include a store-carry and forward feature as part of their recovery method. Some examples that use this feature are Vehicle-Assisted Data Delivery (VADD) protocol [4], Greedy Traffic-Aware Routing (GyTAR) protocol [5], and Border Node based Routing (BBR) protocol [6].

In this paper, we design and implement a routing protocol with a carry and forward feature that is able to deliver data packets with small end-to-end delay without the use of real time traffic data to determine forwarding path, or flooding mechanism. The underlying idea of our protocol design is to forward multiple copies of data packets at road intersections to increase the chance of reaching the destination, and thus reduce the end-to-end delivery delay.

RELATED WORKS

Noting that the carry and forward mechanism can largely influence the end-to-end message delivery delay, majority of VANET routing protocols employ carry and forward method only to ensure intermittent connectivity in a vehicular network does not hinder packet delivery. Further, these protocols design their own unique solution to reduce end-to-end delay. For example, both the Greedy Traffic-Aware Routing (GyTAR) [6] and the Vehicle-Assisted Data Deliver (VADD) [4] protocols rely on traffic density in selecting forwarding path. VADD prefers a high traffic density path to a geographically

shortest path especially, if the geographically shortest path contains partitioned networks, and packets have to be carried by vehicles instead of transmitted via wireless channel. At each intersection, GyTAR dynamically selects the next candidate junction by taking real-time vehicular traffic into account. However, choosing forwarding path with high density paths may not be the optimal solutions in minimizing delivery delay. If all vehicles have the same idea in using high density paths, channel utilizations along these paths will increase, and as a result, packets may either get dropped or incur higher delays

The Distributed Vehicular Broadcast (DV-CAST) [7] and the Border Node based Routing (BBR) [6] protocols use restricted flooding mechanism to deliver packets to the destination vehicles. DV-CAST suppress the flooding procedure in a dense network to avoid redundant broadcast and reduce overhead.

PROACTIVE MULTI-COPY ROUTING PROTOCOL

Protocol design assumption
In our Proactive Multi-Copy (PMC) routing protocol design, we assume that each vehicle has the capability to obtain the road map data and its position information, which we consider as a valid assumption since nowadays most of the vehicles have a Global Positioning System (GPS) device.

In addition, we are assuming the source vehicle acquires the location of the destination vehicle via a location service, which is beyond the scope of our design and will be not discussed in this paper. Once the destination vehicle's location is obtained, the information is carried in the packet so that intermediate nodes do not have to use the location service. However, due to the dynamic nature of a vehicular network, the destination node may have already left the area by the time packets arrive at the initial location. In this case, the packet carrier will obtain the new location of the destination node via a location service and forward the packets toward the new location. Further, we presume the use of a location service is limited only to acquiring the destination node location. Therefore, each vehicle in the network will depend on the beaconing system for its neighbour's information.

Proactive Multi-Copy (PMC) protocol design
The PMC protocol is based on the idea of a carry and forward protocol combining with a single hop beaconing system. In the PMC protocol, packet replication is made only at the intersection in which multiple road paths to the destination are available based on the candidates moving direction and destination vehicle positioning information. At the straight road section where there is no alternative paths, the protocol greedily forwards packets to the next intersection that leads towards the destination.

In this protocol, we assume that each node maintains neighbourhood state information in an nb_table,

which stores the id, the time of the beacon transmission, the current position, the speed, and the velocity of the neighbouring vehicles at the time when the beacon is received. This information is acquired through single-hop beaconing system, where a vehicle would broadcast its information to its single-hop neighbours.

As shown in Figure-1, there are three packets modes in the PMC protocol; greedy forwarding mode, multi-copy forwarding mode, and recovery mode. When a vehicle receives a packet, and the destination vehicle is one of its current neighbour, it immediately transmits the packet to the receiver. Otherwise, the vehicle will determine whether it is located at an intersection or not (intersection_radius). If the vehicle is currently at an intersection, the packet enters the multi-copy forwarding mode. Otherwise, it enters the greedy forwarding mode. In the greedy forwarding mode, the packet carrier finds the best next hop (nexth) via the greedy algorithm with direction awareness. This algorithm will be explained later in this section. In either multi-copy forwarding mode or greedy forwarding mode, if the current vehicle is unable to find the closest node to the destination node other than itself, or also known as local maxima, the packets then enter the recovery mode.
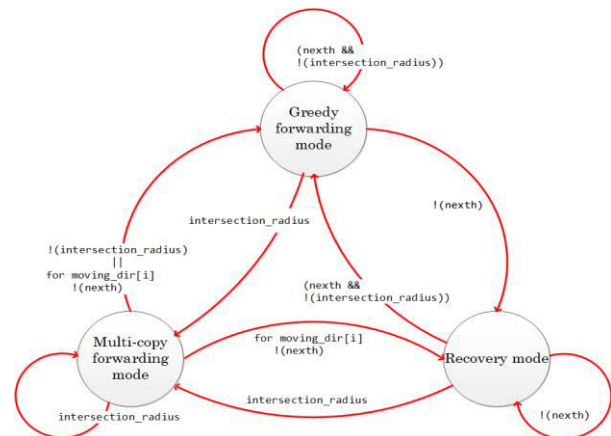

Figure-1. Transition modes in PMC protocol

This situation is commonly happened in a sparse network, where a vehicle may not have any information on its neighbours at all or the neighbours already left its transmission range. In the recovery mode, packets are carried in the buffer and the carrying vehicle will try to retransmit once it receives beacons from its neighbour or when it arrives within other vehicle's transmission range.

Figure-2 demonstrates an example where a source vehicle (v_s) is forwarding data packets to a destination vehicle (v_d). The PMC protocol aims to reduce the delivery delay by proactively replicates data packets at intersections and forward the packets greedily at regular road segments. At any intersection, the PMC protocol replicates the packets through road segments where the road direction ($\vec{R}$) is moving towards v_d.
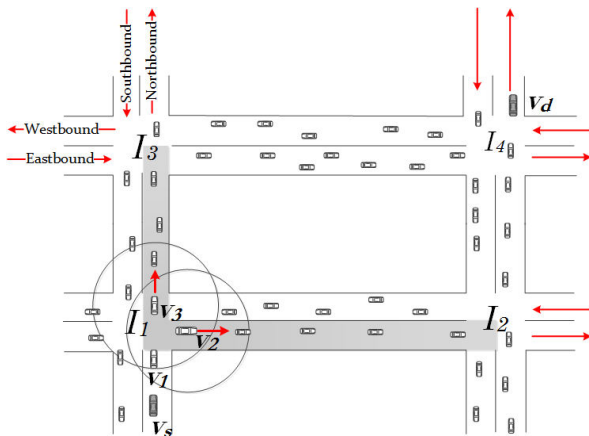
Figure-2. Example scenario for multi-copy forwarding at an intersection

In the PMC protocol, each vehicle has to maintain a *m_copy* table, which has data entries that include data packet id, destination vehicle id, and the location of an intersection at which the corresponding packet is replicated. The use of *m_copy* table is to determine whether or not a data packets has already been replicated and forwarded beforehand in a particular intersection.

In Figure-2, after v_1 receives a data packet n ($DPkt_n$) from v_s at intersection I_1, it verifies whether or not $DPkt_n$ has been replicated and forwarded at I_1 previously. If $DPkt_n$ has been replicated at I_1 before, v_1 drops $DPkt_n$. Otherwise, v_1 implements multi-copy forwarding, by examining of each road segment at I_1 to find out which of the four directions are moving toward v_d. In the example scenario, road segment I_{13} with Northbound direction and I_{13} with Eastbound direction which are greyed out in the Figure-2, are the best road segment candidates for packet replication. Henceforth, using greedy algorithm with direction awareness, v_1 finds the next hop from its neighbouring vehicles for the selected road segments and forwards the packets to the selected next hop vehicles, which in the example v_2 and v_3. After v_1 replicates $DPkt_n$ and forwards to v_2 and v_3, both v_2 and v_3 forward $DPkt_n$ to road segments r_{12} and r_{13}, respectively via greedy forwarding with direction awareness. After forwarding packets to v_2 and v_3, v_1 stores $DPkt_n$, v_d and I_1 information in the *m_copy* table. This process is then repeated once $DPkt_n$ reaches intersections I_2 and I_3.

Majority of forwarding algorithms in VANET have ascertained that greedy forwarding is not enough to find a suitable next hop vehicle (v_{nexth}) [4]–[7]. In a normal greedy forwarding, an intermediate node that is closest to the destination node becomes the next relay in the packet forwarding process. However, the PMC protocol also considers the moving direction of the candidate vehicles when choosing v_{nexth}. To determine whether a candidate vehicle is moving towards or away from v_d, we utilize Equation (1) to calculate the moving direction of a candidate vehicle for v_{nexth}.

$$\theta = |\phi - \varphi| \leq \frac{\pi}{2}, \tag{1}$$

where

$$\phi = \arctan\left(\frac{(\overrightarrow{v_k})_y}{(\overrightarrow{v_k})_x}\right) \text{ and } \varphi = \arctan\left(\frac{(\overrightarrow{v_k v_d})_y}{(\overrightarrow{v_k v_d})_x}\right).$$

Equation (1), $\overset{\text{uur}}{v_k}$ is a vector that indicates a candidate vehicle speed value and moving direction. We define variable $\overset{\text{uuur}}{v_k v_d}$ as the distance vector from v_k and v_d. If θ is smaller than or equal to π/2, than we consider the current vehicle is moving towards the destination vehicle. However, relying exclusively on θ in Equation (1) is not enough to determine whether v_k is moving towards or away from v_d. The current forwarder also needs to discover the cardinal direction of a candidate vehicle, v_k, before calculating θ. Figure-3 displays an example scenario why discovering cardinal direction of a vehicle candidate is important for directive awareness. Each cardinal direction shown in Figure-3 is assigned with an angle of the polar coordinate system; North = 90°, South = 270°, East = 0°, and West = 180°.
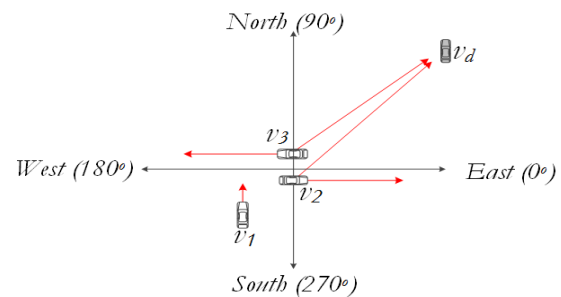

Figure-3. Example scenario for directive awareness algorithm.

In Figure-3, both v_2 and v_3 are suitable next hop candidates for v_1. Without discovering the cardinal direction for v_2 and v_3, the calculation of θ from Equation (1) will result in 0° for both v_2 and v_3, since both and have zero value. By identifying the cardinal directions for v_2 and v_3, the calculation for $\theta_{v_2 v_d}$ and $\theta_{v_3 v_d}$ are as follows:

$$\theta_{v_2 v_d} = |0° - \varphi_{v_2 v_d}| \quad \text{and} \quad \theta_{v_3 v_d} = |180° - \varphi_{v_3 v_d}|$$

where
$\varphi_{v_2 v_d}$ and $\varphi_{v_3 v_d}$ can be calculated from φ in Equation (1)

SIMULATION FRAMEWORK

Both PMC and single-copy forwarding protocols are implemented in the network simulator NS-2 [8], [9] for performance assessment. The simulation scenarios are configured in a 3 by 3 km urban grid model (Refer to Figure-4) with five different densities ranging from 50 vehicles to 175 vehicles. We use the VanetMobiSim Intelligent Driver Model with Lane Changing (IDM_LC)

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[10] to generate realistic vehicle mobility with maximum speed of 15 m/s. Using this model, each vehicle is able to adjust its speed based on the movement of the neighbouring vehicles and change lane to overtake other vehicles in multi-lane roads. This model also supports smart intersection management, where vehicles slow down and stop at intersections, or they act accordingly at traffic lights. Table-1 summarizes the configuration parameters used in the simulation. The communication range is set at 250 meters and all vehicles are required to broadcast beacon packets every 0.5 second. Five pairs of source and destination vehicles are selected in random and each source transmits one data packet for every two seconds.
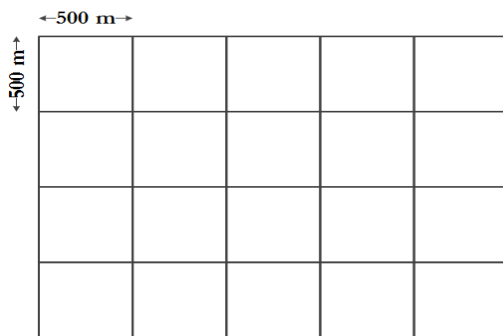

Figure-4. Manhattan grid topology used in the simulation.

Table-1. Network model configuration.

Area	3 km by 3 km
Number of vehicles	50, 75, 100, 125, 150, 175
Speed (meter/sec)	Between 5 to 15 m/s
Simulation time	1000 seconds
Number of connections	5
Traffic pattern	CBR traffic
Packet size	256 bytes
Beacon interval	0.5 seconds
Propagation model	Two Ray Ground model
MAC layer	IEEE 802.11b
Transmission range	250 meters

The PMC protocol uses a single-hop beaconing system to acquire knowledge on local topology. However, we design the PMC protocol with a fixed beaconing system since the routing overhead is not the research focus in this paper [11].

Performance metrics

For each scenario, we execute our simulation with 100 iterations to ensure statistical validity for 95% confidence interval. The performance assessment is based on four metrics:

1. **Packet delivery ratio:** Measures the fraction of data packets that are successfully received by destination to those generated by traffic source.
2. **Average end-to-end delay:** Measures the average difference between the time a data packet is originated

by an application and the time the same packet arrives at its destination.
3. **Routing overhead ratio:** Measures the fraction of total beacon packets emitted to total number packets transmitted in the network.
4. **Total collision ratio:** Measure the ratio of total number of collisions to total number of packets transmitted in the network

SIMULATION RESULTS AND ANALYSIS

Figure-5 to 8 presents the simulation results on performance comparison between the PMC protocol and the single-copy forwarding algorithm.
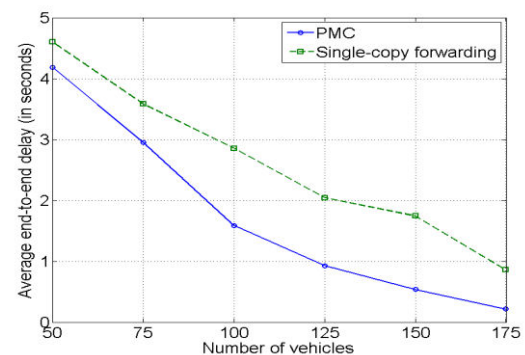

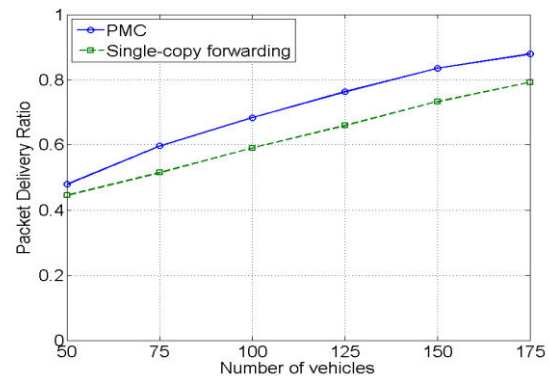**Figure-5.** Simulation result on average end-to-end delay (in seconds).

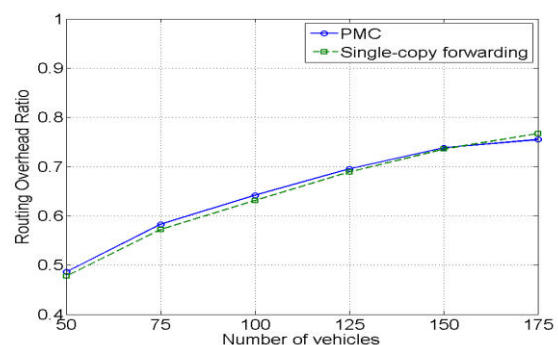**Figure-6.** Simulation result packet delivery ratio.

Figure-7. Simulation result on routing overhead ratio.
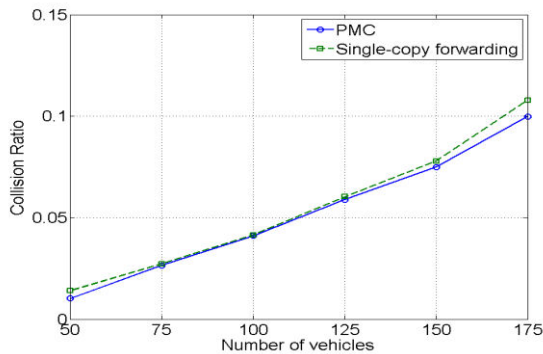
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Figure-8. Simulation result on collision ratio.

Figure-7 and 8 display the comparison overhead and collision ratios between PMC and single-copy forwarding in the simulation, respectively. In the figures, PMC and single-copy forwarding show similar overhead and collision ratios while achieving lower end-to-end delay. Even though the number of vehicles increases in a dense network, the PMC protocol is still able to maintain similar overhead ratios as single-copy forwarding since PMC uses the same beaconing system as single-copy forwarding with only small additional bytes of information added to the beacon packet.

CONCLUSIONS
In this paper, we presented a new proactive multi-copy (PMC) routing protocol that reduces end-to-end delay by proactively replicates data packets at intersections and forwards them to different intermediate nodes. By forwarding multiple copies of packets to different relays at different road segments, the protocol increases the chance of reaching the destination at low delivery delay. The forwarding mechanism is based on information that is commonly available via a GPS device. Simulation in an urban grid model has shown that the PMC protocol is able to reduce the average end-to-end delay and increase the delivery ratio compared to single-copy forwarding results. Despite having additional information added to beacon packets to minimize redundant replication, the results have shown that the proposed protocol is able to maintain similar overhead and collision ratios as the single-copy forwarding algorithm

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