PreZcast: A Preferred-Zone Based Broadcast Protocol for Urban Areas of VANETs

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***Abstract*—Broadcasting is an important routing strategy for message delivery in a VANET. However, the broadcast storm caused by loads of duplicate data packets can be severe, which leads to intense contention among vehicle nodes and a large number of dropped packets. In this case, the efficiency of message delivery is limited. This paper considers a broadcast routing protocol specially designed for urban areas with dense traffic and a huge amount of data traffic, and proposes a Preferred-Zone based broadcast (PreZcast) protocol. To alleviate the broadcast storm and improve the efficiency of message delivery, PreZcast only allows neighbors located within a Preferred Zone (PreZ) of a source node to rebroadcast a received packet. The PreZ is chosen based on the initial location and the distribution of two-hop neighbors of the source node. To further validate PreZcast in a more realistic and irregular topology, we evaluate PreZcast with real datasets issued from Bologna road traffic. Moreover, MultiPoint Relay (MPR) is introduced to further reduce duplicate packets in the network. Simulation results show that as compared with the Flooding protocol, PreZcast approximately improves 15% of broadcast efficiency and reduces 65% of packets transmitted with 5% more energy consumption, while PreZcast with MPR improves 10% of broadcast efficiency and reduces 70% of packets transmitted with only 0.5% more energy consumption.**

***Index Terms*—broadcast; routing; PreZcast; urban areas; VANET**

I. Introduction

Vehicular Ad Hoc Networks (VANETs) are considered as a major component of future intelligent transportation systems (ITSs) [1]. In VANETs, Connected and Automated Vehicles (CAVs) are equipped with On-Board Units (OBUs) and are provided with varieties of applications, including safety related, non-safety related and infotainment applications [2]. To implement those applications, timely delivery of relevant messages or data packets need to be guaranteed. Thus, it is necessary to design an efficient routing protocol which can timely deliver a data packet to as many vehicles as possible.

Broadcasting is an important routing strategy for message delivery in a VANET, especially for message delivery of safety related services [3]. In broadcasting, a data packet is sent from a source node and rebroadcast by all nodes which receive the packet until the destination node is reached. Broadcasting is easier to implement in comparison with unicasting and multicasting and can achieve a high packet delivery rate. However, the broadcast storm problem caused by loads of duplicate data packets can be severe and may lead to intense contention among nodes and thus limit the efficiency of message delivery [4]. Therefore, it is necessary to design an efficient broadcasting protocol to alleviate the broadcast storm problem and improve the efficiency of message delivery in the network.

In this paper, we propose a new broadcasting protocol, a Preferred-Zone based broadcast (PreZcast) protocol, for data dissemination in urban scenarios of a VANET with dense traffic and a huge amount of data traffic. To alleviate the broadcast storm and improve the efficiency of message delivery, PreZcast only allows neighbors located within a Preferred Zone (PreZ) of a source node to rebroadcast received data packets. The PreZ is chosen for the source node according to the source node's initial location and the distribution of the source node's two-hop neighbors. Simulation experiments are conducted to evaluate the performance of the PreZcast protocol using OMNeT++-5.7 (Objective Modular Network Testbed in C++), which provides a great support for simulating a real physical environment. To further validate PreZcast in a more realistic and irregular topology, we implement PreZcast using real traffic datasets of Bologna. Moreover, the MultiPoint Relay (MPR) mechanism [5] is introduced to further reduce duplicate packets in the network. Simulation results show that as compared with the Flooding protocol, PreZcast can approximately improve 15% of broadcast efficiency and reduce 65% of packets transmitted with 5% more energy consumption, while PreZcast with MPR can improve 10% of broadcast efficiency and reduce 70% of packets transmitted with only 0.5% more energy consumption.

This paper is organized as follows. Section II reviews related work on broadcast protocols for VANETs. Section III presents the PreZcast protocol and its combination with MPR. Section IV shows simulation results to evaluate the performance of PreZcast. Section V concludes this paper.

II. Related Work

Broadcast routing protocols have always been one of the research focuses of VANETs [6]–[11].

In [6], Zhang et al. proposed an opportunistic broadcast protocol considering a delayed retransmission mechanism and a relay selection mechanism based on the expected broadcast speed, which alleviates the negative effects of retransmissions of previous forwarders and redundant relays of packets. However, only a straight road without intersections is considered. In [7], Zhang et al. proposed a Concurrent Transmission based Broadcast (CTB) protocol, which is based on the analysis of the maximum temporal displacement of concurrent transmissions. CTB is composed of broadcasting on the streets and broadcasting at intersections. However, it is required that all nodes transmit identical packets, which is not practical for future ITS. In [8], Tei et al. proposed a Multi-criteria based Relay Election Protocol for urban scenarios. The selection of relays is based on a multi-criteria function, which considers system parameters like SNR, distance between the transmitting node and the receiving node, etc. As the density of nodes increases, however, the computation complexity of the multi-criteria function increases, and accordingly, the performance of the proposed protocol deteriorates. In [9], Nguyen et al. proposed an RSU-assisted IEEE 802.11p-based multi-channel MAC protocol, where an RSU is used to calculate the optimized control channel (CCH) interval and track transmissions of safety messages. Obviously, the coverage of RSUs needs to be guaranteed. In [10], Lei et al. dealt with the severe collision problem of 802.11p MAC protocol from the prospective of MAC layer. A hybrid access method was proposed, which is based on time slot reservations and implicit feedbacks. In [11], Srivastava et al. proposed a fuzzy-based beaconless probabilistic broadcasting protocol, where the forwarding probability of relaying nodes is determined by parameters like their moving direction, buffer loading delay, etc. However, only a grid topology is investigated.

To the best of our knowledge, PreZcast is different from most existing broadcast protocols in that it is specially designed for urban road scenarios, which makes full use of the urban topology in order to guarantee timely delivery of messages.

III. Preferred-Zone Based Broadcast Protocol

In this section, we present the proposed PreZcast protocol for urban areas of a VANET as well as its variant when combined with MPR.

To better describe the protocol, we first introduce the following notations. For a source node v, we have

- $PreZ(v)$: a PreZ selected for v
- $PreZ_k$: a sub-PreZ of $PreZ(v)$
- (X_{PreZ_k}, Y_{PreZ_k}): the coordinate of $PreZ_k$'s center
- R_{sub}: the range of a sub-PreZ
- (X_0^v, Y_0^v): the coordinate of the intersection closest to v (as shown in Fig. 1)
- $\mathbb{K}_{int}$: the set of directions of all branches at (X_0^v, Y_0^v). As shown in Fig. 1, we have $\mathbb{K}_{int}$ = {North, South, East, West}.
- $|\mathbb{K}_{int}|$: the cardinality of the set $\mathbb{K}_{int}$, i.e., the number of branches at (X_0^v, Y_0^v).

Thus, we have

$$PreZ(v) = \bigcup_{k\in\mathbb{K}} PreZ_k, \mathbb{K} \subset \mathbb{K}_{int}, \quad (1)$$

i.e., a $PreZ(v)$ consists of $|\mathbb{K}|$ sub-PreZs selected from $|\mathbb{K}_{int}|$ candidate sub-PreZs. As shown in Fig. 2, we have $PreZ(v) = PreZ_{West} \cup PreZ_{South}$. Also, we define $PreZ_k$ as a triple, $(X_{PreZ_k}, Y_{PreZ_k}, R_{sub})$.

- $\mathbb{N}(v)$: the set of v's neighbors
- Φ_k: the set of v's neighbors located on the branch in direction k (as shown in Fig. 1)
- Φ_{PreZ}: the set of v's neighbors located within $PreZ(v)$
- $\mathbb{M}(v)$: the MPR set of v
- $\mathbb{N}(\Phi)$: the set of nodes that can be reached by all nodes in set Φ (i.e., $\forall x \in \Phi$), i.e.,

$$\mathbb{N}(\Phi) = \left[\bigcup_{x\in\Phi} \mathbb{N}(x)\right] \setminus \Phi \quad (2)$$

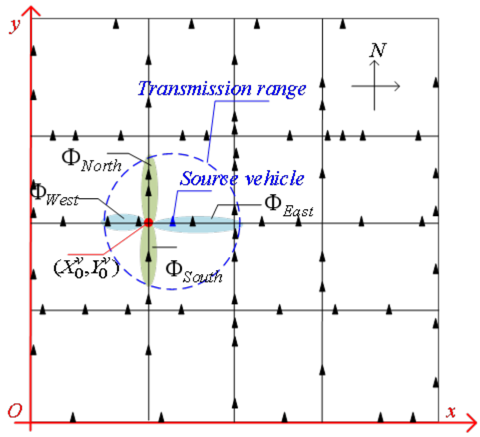

Fig. 1. Illustration of $\Phi_k (k \in \mathbb{K}_{int} =$ {North, South, East, West}).

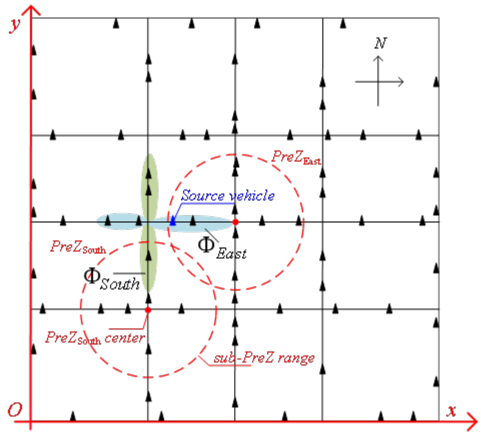

Fig. 2. Illustration of $PreZ_k$.

A. Description of the PreZcast Protocol

The underlying idea of PreZcast is that identifying a PreZ helps reducing duplicate packets in the network while maintaining the number of nodes reached. To this end, the PreZcast protocol only allows neighbors located within a PreZ to rebroadcast received data packets, thus alleviating the broadcast storm. The PreZ is chosen for a source node based on the initial position of the source node and the distribution of two-hop neighbors of the source node. The major procedures of PreZcast run at a source node and a receiving node are described by Process 1 and 2, respectively.

When a source node v has a data packet to send, it needs to select a PreZ, i.e., $PreZ(v)$, before broadcasting the packet. As mentioned before, a $PreZ(v)$ consists of $|\mathbb{K}|$ sub-PreZs selected from $|\mathbb{K}_{int}|$ candidate sub-PreZs. The first sub-PreZ $PreZ_{k_1}$ is selected such that the nodes which can be reached by all nodes in $PreZ_{k_1}$ are the most. The rule for selecting the other $(|\mathbb{K}|-1)$ sub-PreZs, $PreZ_k(k \in \mathbb{K}, k \neq k_1)$, is to make $\mathbb{N}(\Phi_k)$ and $\mathbb{N}(\Phi_{PreZ})$ have the minimum number of duplicate nodes. The sub-PreZ range, R_{sub}, is pre-defined. Thus, after the sub-PreZs are chosen, the information on $PreZ(v)$, i.e., $(X_{PreZ_k}, Y_{PreZ_k}, R_{sub})$, $\forall k \in \mathbb{K}$, will be added to a packet transmitted by v.

Process 1 PreZcast Protocol run at a source node v when it has a data packet to send

S1: Set (X_0^v, Y_0^v) at the intersection closest to v.
S2:
$k_1 \leftarrow arg \max_{k(k \in \mathbb{K}_{int})} |\mathbb{N}(\Phi_k)|$;
Set $PreZ_{k_1}$ at the nearest intersection in direction k_1 to (X_0^v, Y_0^v), and record $(X_{PreZ_{k_1}}, Y_{PreZ_{k_1}})$;
$PreZ(v) \leftarrow PreZ_{k_1}$;
$i \leftarrow 1$;
S3:
while $i < |\mathbb{K}|$
for all $k \in \mathbb{K}_{int}$
$k_2 \leftarrow arg \min_{k(k \neq k_1, |\Phi_k| \neq 0)} |\mathbb{N}(\Phi_k) \cap \mathbb{N}(\Phi_{PreZ})|$;
Set $PreZ_{k_2}$ at the nearest intersection in direction k_2 to (X_0^v, Y_0^v), and record $(X_{PreZ_{k_2}}, Y_{PreZ_{k_2}})$;
$PreZ(v) \leftarrow PreZ(v) \cup PreZ_{k_2}$;
$i \leftarrow i + 1$;
end for
end while
S4:
Broadcast packet P periodically with frequency λ_0, which contains the information on $PreZ(v)$, i.e., $(X_{PreZ_k}, Y_{PreZ_k}, R_{sub})$, $\forall k \in \mathbb{K}$.

Upon reception of a packet P from v, a receiving node u extracts the information on $PreZ(v)$ from P and determines whether it is located within $PreZ(v)$. If it is the first time that u receives P, u will forward P (i.e., Line 2 of Process 2); if it is not the first time and u is located within $PreZ(v)$, u will rebroadcast P (i.e., Line 5 of Process 2); otherwise, u will drop the packet (i.e., Line 7 of Process 2).

Process 2 PreZcast Protocol run at a receiving node u upon reception of a packet P containing $(X_{PreZ_k}, Y_{PreZ_k}, R_{sub})$, $\forall k \in \mathbb{K}$.

1: **if** $B_f = 0$ **then**
2: forward P;
3: $B_f \leftarrow 1$;
4: **else if** $u \in \Phi_{PreZ}$ **then**
5: forward P;
6: **else**
7: drop P;
8: **end if**
9: return;

B. Description of the PreZcast Protocol with MPR

To further reduce duplicate packets in the network, the MultiPoint Relay (MPR) mechanism is introduced [5].

A node selects its MPRs in such a way that all its two-hop neighbors can be reached by its MPRs. Thus, only the nodes in the MPR set are allowed to forward received packets. The selection of MPRs for v is described as Process 3, and the PreZcast protocol with MPR run at a receiving node is described as Process 4. Note that the process of PreZcast with MPR run at a source node is the same as that of PreZcast.

Process 3 MPR selection for a source node v

$\mathbb{M}(v) \leftarrow \emptyset$;
$\mathbb{M}_1 \leftarrow \Phi_{PreZ}$;
$\mathbb{M}_2 \leftarrow \mathbb{N}(\Phi_{PreZ})$;
$D_x \leftarrow |\mathbb{N}(x) \setminus \mathbb{M}_1|$ for a node x;
S1:
for all $x \in \mathbb{M}_1$
$D_x \leftarrow |\mathbb{N}(x) \setminus \mathbb{M}_1|$;
end for
S2:
for each $x \in \mathbb{M}_1$:
if $\exists y \in \mathbb{M}_2$ can only be reached by v through x **then**
add x into $\mathbb{M}(v)$;
$\mathbb{M}_2 \leftarrow \mathbb{M}_2 \setminus \mathbb{N}[\mathbb{M}(v)]$;
end for
S3:
if $\mathbb{M}_2 \subseteq \mathbb{N}[\mathbb{M}(v)]$ **then**
return;
else
for all $x \in \mathbb{M}_1$
$R_x \leftarrow D_x - |\mathbb{N}[\mathbb{M}(v)]|$;
end for
add x with the largest R_x and the largest D_x into $\mathbb{M}(v)$;
$\mathbb{M}_2 \leftarrow \mathbb{M}_2 \setminus \mathbb{N}[\mathbb{M}(v)]$;
return to **S2**;
end if

Process 4 PreZcast Protocol with MPR run at a receiving node u upon reception of a packet P

if $B_f = 0$ **then**
forward P;
$B_f \leftarrow 1$;
else if $u \in \Phi_{PreZ}$ and $u \in \mathbb{M}(v)$ **then**
forward P;
else
drop P;
end if
return;

IV. Performance Evaluation

In this section, we evaluate the performance of the proposed PreZcast protocol and that of the PreZcast protocol with MPR through simulation results.

The simulation experiments were conducted using OMNeT++-5.7, which provides a great support for simulating a real physical environment. In the experiments, we considered the signal power loss caused by objects in the environment of an urban scenario, which is ignored in most existing work, and used the $PhysicalEnvironment$ module to simulate the environment. Moreover, we select $IdealObstacleLoss$ as the obstacle loss model of the environment, and $FreeSpacePathLoss$ as the path loss model of the environment. Traffic in the simulation experiments is generated using SUMO-1.8 [12]. Vehicles follow an arrival rate of 1/VAP (Vehicle Arrival Period) per second. IEEE 802.11p is used as the underlying MAC protocol. The parameters used in the simulations are summarized in Table I. For road scenarios, we consider an urban grid scenario and a road scenario of Bologna.

TABLE I
PARAMETER VALUES

Frequency	5.9GHz
Transmission power	10mW
Total number of nodes	Grid:150, Bologna:250
Simulation area	Grid:2000m×2000m Bologna:2000m×1350m
Vehicle Arrival Period (VAP)	0.5
Broadcast frequency	10pps

In performance evaluation, broadcast efficiency is introduced as a metric to measure the efficiency of message delivery, which is defined as the number of nodes that receive a packet generated by a source node to the total number of nodes in the network.

A. Urban Grid Scenario

As shown in Fig. 3, we consider an urban grid scenario, where all streets have two lanes in opposite directions. Two sub-PreZs are selected in this scenario, i.e., $|\mathbb{K}| = 2$, which has been validated as the optimal configuration for improving the system performance through simulation experiments.

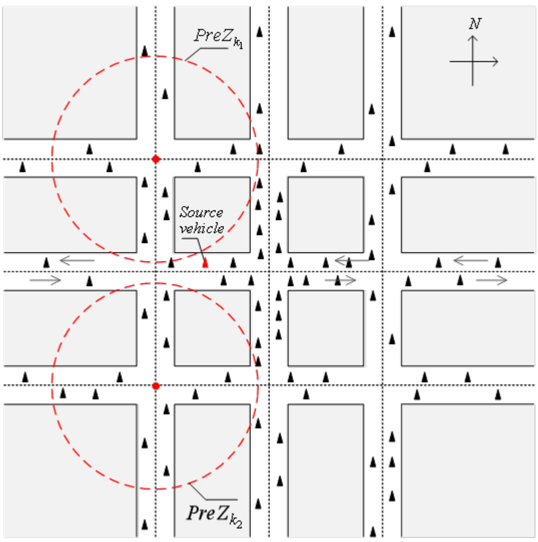

Fig. 3. Urban grid scenario.

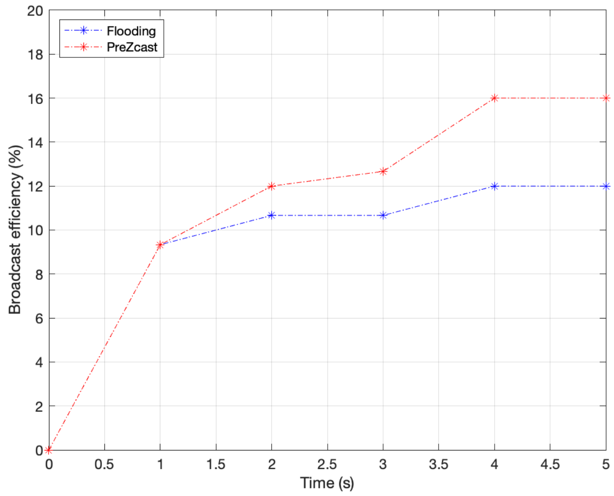

Fig. 4. Broadcast efficiency vs time (P_t=10mW, R_{sub}=400m).

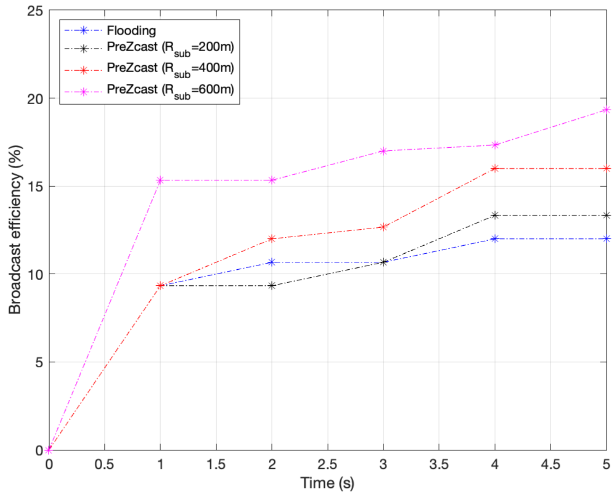

Fig. 5. Broadcast efficiency vs time (P_t=10mW).

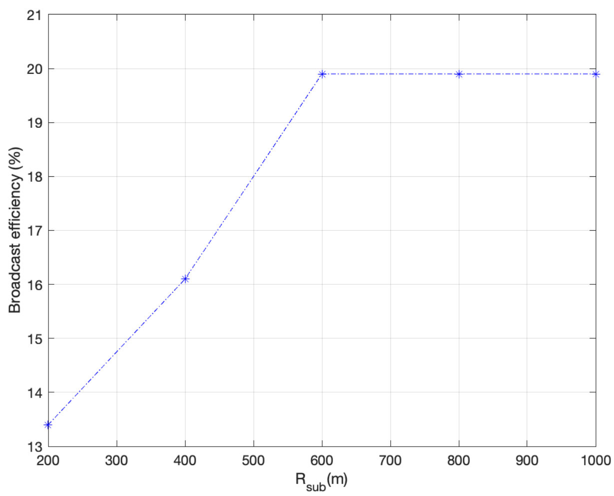

Fig. 6. Broadcast efficiency vs R_{sub} (P_t=10mW).

Fig. 4 shows the change of the broadcast efficiency over time. It can be seen that as time goes by, the broadcast efficiency increases, i.e., more nodes are reached. Obviously, PreZcast achieves a higher broadcast efficiency within a shorter time. This is because the Flooding protocol causes a severe broadcast storm, and thus the number of nodes that can be reached is limited.

Fig. 5-6 show the impact of the sub-PreZ range R_{sub} on the broadcast efficiency. It can be seen in Fig. 5 that as time goes by, the broadcast efficiency increases. On the other hand, different values of R_{sub} have different impacts on the broadcast efficiency, and for R_{sub}=600m, the improvement of the broadcast efficiency is the largest. In Fig. 6, it can be seen that as R_{sub} increases, the broadcast efficiency increases until it reaches an upper limit when $R_{sub} \geq$600m. Thus, in the following experiments, we set R_{sub}=600m.

B. Bologna Road Scenario

To further validate PreZcast in a more realistic and irregular topology, we implement PreZcast in a Bologna road scenario [13], where the road topology is shown in Fig. 7.

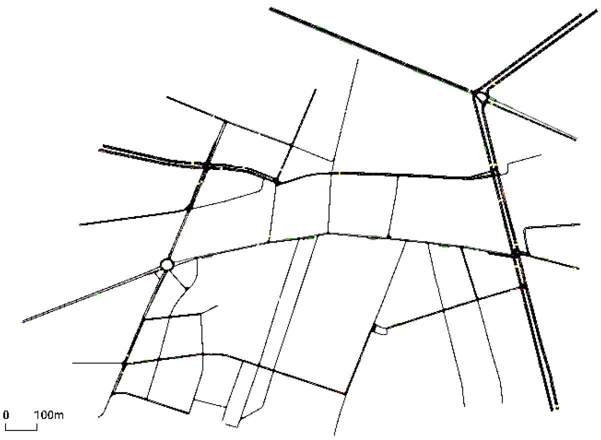

Fig. 7. Bologna road scenario.

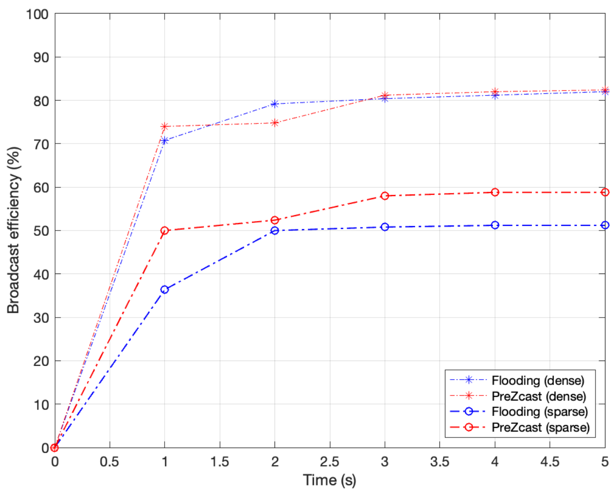

Fig. 8. Broadcast efficiency vs time (P_t=10mW,R_{sub}=600m).

Fig. 8 shows the impacts of sparse vehicle distribution and dense vehicle distribution on the broadcast efficiency, respectively. It can be seen that PreZcast also works for the Bologna scenario. On the other hand, when vehicles are densely distributed, the broadcast efficiency of both protocols is larger than that when vehicles are sparsely distributed. Furthermore, it can be seen that the improvement of PreZcast in the Bologna scenario is limited, as compared to that in Fig. 4. This is because in the Bologna scenario, vehicles tend to stay in swarms and might get isolated from other swarms.

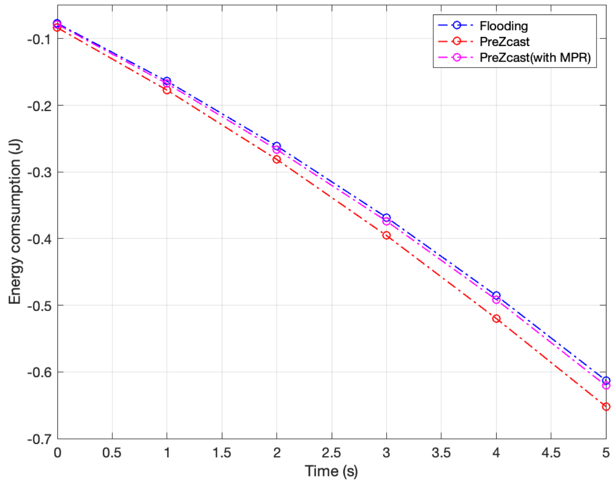

Fig. 9. Energy consumption vs time (P_t=10mW,R_{sub}=600m).

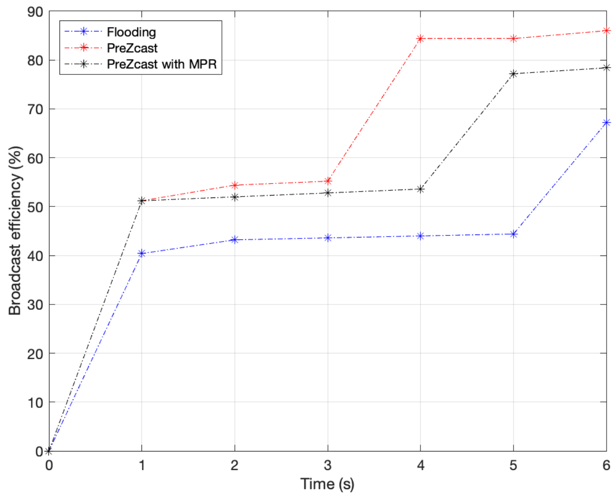

Fig. 10. Broadcast efficiency vs time (P_t=10mW,R_{sub}=600m).

To further reduce duplicate packets in the network, the MPR mechanism is introduced. As shown in Table II, PreZcast with MPR reduces the number of packets transmitted in the network and improves the Packet Received Rate (PRR). This is because with MPR, fewer nodes are responsible for message rebroadcasting.

TABLE II
PACKET RECEIVED RATE (PRR) OF DIFFERENT PROTOCOLS.

	Packet sent	**Packet received**	**PRR**
Flooding	642	104	16.20%
PreZcast	224	127	56.69%
PreZcast with MPR	195	121	62.05%

Fig. 9 shows the average energy consumption of nodes in the network. It can be seen that PreZcast is the most energy consuming. This is because with PreZcast, nodes within $PreZ(v)$ are responsible for rebroadcasting, and thus consume more energy. According to Fig. 9-10, PreZcast with MPR cannot improve the broadcast efficiency as much as PreZcast, but it reduces the average energy consumption, which is critical for some vehicles with limited energy.

To sum up, PreZcast can improve the broadcast efficiency as compared to the Flooding protocol, which however comes at a price of higher energy consumption. PreZcast with MPR can save energy consumption at the expense of the broadcast efficiency. The proposed two routing protocols can well satisfy different application requirements of vehicles.

V. Conclusions

In this paper, we proposed a Preferred-Zone based broadcast (PreZcast) protocol for VANETs in urban areas. To alleviate the broadcast storm and improve the efficiency of message delivery, PreZcast only allows neighbors located within a PreZ chosen for a source node to rebroadcast a data packet. The PreZ is chosen based on the initial location of the source node and the distribution of its two-hop neighbors. To further validate PreZcast in a more realistic and irregular topology, we evaluate PreZcast with real datasets issued from Bologna road traffic. Moreover, MultiPoint Relay (MPR) is introduced to further reduce duplicate packets in the network. Simulation results show that as compared with the Flooding protocol, PreZcast approximately improves 15% of broadcast efficiency and reduces 65% of packets transmitted with 5% more energy consumption, while PreZcast with MPR improves 10% of broadcast efficiency and reduces 70% of packets transmitted with only 0.5% more energy consumption. In future work, we will consider a more complex scenario with RSUs or other network infrastructure.

Acknowledgment

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