Streetcast: An Urban Broadcast Protocol for Vehicular Ad-Hoc Networks

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Abstract—Vehicular Ad-hoc NETworks (VANETs) adopting Dedicated Short-Range Communications (DSRCs) have emerged as a preferred choice of network design for the Intelligent Transportation System (ITS). A possible application of the ITS is to disseminate emergency messages by multihop broadcast. Due to the high density and high mobility of vehicles, it is difficult to design an efficient broadcast protocol for VANETs in urban areas. In this work, we propose a broadcast protocol, named Streetcast, to provide efficient broadcast service. Street maps are used to assist the selection of relay nodes, and multicast RTS (Request-To-Send) is adopted to protect wireless communications for providing high reliability. In addition, an adaptive beacon control heuristic is proposed to reduce beacon overheads. At last, we evaluate our broadcast protocol in a real roadmap scenario with real traffic flows. The simulation results show that the proposed broadcast protocol has a superior performance in terms of packet delivery ratio and the number of collisions under various traffic load patterns.

Index Terms—Localized broadcast, Streetcast, VANETs

I. INTRODUCTION

Vehicular Ad-hoc NETworks (VANETs) are a special form of Mobile Ad-hoc NETworks (MANETs). VANETs are different from MANETs in several ways. First, vehicles are in a large volume, and network topology changes rapidly. Second, the mobility of vehicles is constrained by roads with limitations on driving speed. Although vehicles can move in high speeds, their directions and speeds are predictable. Third, vehicles usually do not have tight energy budget. Instead, bandwidth issues are more critical than energy ones in VANETs.

VANETs adopting Dedicated Short-Range Communications (DSRCs) have emerged as a preferred choice of network design for the Intelligent Transportation System (ITS). The Federal Communications Commission (FCC) recently allocated 75 MHz in 5.9 GHz band for the Vehicle-to-Vehicle (V2V) and Vehicle-to-Roadside-unit (V2R) communications. Moreover, it is predicted that the number of telematics subscribers in the United States will reach more than 15 million in the future [1]. The VANET will undoubtedly play an important role in next-generation networks.

The main purposes of ITS include providing real-time and comprehensive traffic information, and to give driving directions. In general, the traffic information can be classified into three categories: beforehand information, real-time information and afterward information. One of the most important services among them is emergency message dissemination. Emergency messages are useful for drivers in hazardous situations, e.g., dangerous road surface conditions, accidents and unexpected fog banks. Such messages are usually time-sensitive and localized. These messages can be disseminated to intended locations through multi-hop broadcast.

Broadcast is a frequently used method for applications running on wireless environments. However, uncontrolled broadcasts will lead to broadcast storm problems [2], which cause severe packet collisions and redundancy and hidden terminal problems. Due to the high density and mobility of vehicles, designing an efficient broadcast protocol for VANETs in urban areas is a big challenge. Recently, there are many researches working on multi-hop broadcast problems in the VANETs. Khakbaz and Fathy [3] proposed a relay-point selection mechanism to reduce broadcast redundancy and collision. The relay-point selection is an important issue for VANET broadcast.

The two major challenges of broadcast are to ensure the reliability of messages while disseminating messages over the intended regions and keeping the delay time within the requirements of the applications. The design of broadcast protocols should exploit the peculiar features that differentiate VANETs from MANETs. In this paper, we propose a MAC broadcast protocol, named Streetcast, to meet the requirements and to relieve the broadcast storm problems. The digital street map information is used to assist the selection of relay nodes, and Multicast Request-To-Send (MRTS) [4] [5] is used to improve the reliability of messages between the sender and selected relay nodes and to avoid collisions and hidden terminal problems. In addition, an adaptive beacon control heuristic is proposed to reduce excessive beacon broadcasts.

The rest of this paper is organized as follows. In Section II, we introduce related works. In Section III, we present our Streetcast algorithm. Section IV contains simulation results and analyses. Conclusions are given in Section V.
II. RELATED WORKS

Network-wide broadcast is needed in many MANET routing protocols to establish routing paths, e.g., Dynamic Source Routing (DSR), Ad-hoc On-demand Distance Vector routing (AODV), Zone Routing Protocol (ZPR), and Location Aided Routing (LAR). These protocols all rely on a simplistic form of broadcasting called flooding, in which each node (or each node in an area) relays every received non-duplicated packet once. However, flooding typically causes bandwidth congestion as well as inefficient use of radio resources. These are called the broadcast storm problems. In dense networks, these problems become more severe. Broadcasting schemes are classified as simple flooding, probability based, area based, and neighbor knowledge based, and their performance were compared through simulations in [6].

In VANETs, multi-hop broadcasting can be used to disseminate safety and emergency warning messages in a specified region and to exchange neighborhood information queries. Various broadcast and flooding protocols, e.g., [7] [8] [9] [10], have been proposed and evaluated in terms of their reliability. Unfortunately, flooding mechanisms in many cases, especially in urban areas, cause significant transmission overhead due to excessive redundancy. To avoid the well-known broadcast storm problem, most broadcasting protocols developed for VANETs select only a limited number of nodes to relay broadcasting data. Geographic information, e.g., node positions and moving directions, and directions of roadway segments, is utilized to select relay nodes in [7] [8].

Vector-based TRAck DEtection (V-TRADE) [8] is one of the earliest examples of broadcasting in VANETs. Each vehicle maintains a border set by classifying its neighbors based on their positions and moving directions and selecting one border node from each class. Border vehicles will help relay broadcast packets. Due to the excessive control overhead for collecting the positions of neighbor vehicles (including those traveling in the opposite direction), the feasibility of V-TRADE is limited. In the meanwhile, Role-based Multicast [7], a form of flooding, enforces nodes to rebroadcast non-duplicated packets exactly once after a waiting time.

Urban Multi-hop Broadcast (UMB) [9] segmented a road in the direction of message dissemination and selected a relay node in the farthest segment by Request To Broadcast (RTB) and Clear To Broadcast (CTB) messages. The directional broadcast works as follows. A source broadcasts an RTB with its position to its neighbors. When neighbors receive the RTB, they calculate their distances to the source and reply a Black-Burst. Each node sends its black-burst in the shortest possible time. At the end of the black-burst, it listens to the channel. Only when the channel is clear does the node take the responsibility to reply a CTB packet. When the source gets the CTB packet, it broadcasts a DATA and waits for an ACK from the node which transmits the CTB packet. The RTB/CTB/ACK handshakes provide clear wireless channels and reliability, and avoid collisions in broadcasting. Note that UMB ensures the farthest node be the relay node. However, the black-burst overheads and the time handshake latency are both negligible. Another disadvantage of UMB is that it uses repeating broadcasts at intersections, resulting in waste on bandwidth. Recently, a broadcast protocol called “TLO” (The Last One) was proposed [10]. “TLO” tries to find the most suitable vehicle to rebroadcast messages. Nodes equipped with GPS send alert messages with their positions and receivers can calculate their distances to the senders. TLO chooses the farthest one as the relay node.

In this work, we propose a broadcast protocol for VANETs in urban areas. The proposed protocol not only adopts the concept of RTB/CTB/ACK handshakes, but also combines the geographic information into the relay-node selection strategy to relieve the transmission redundancy.

III. STREETCAST

Streetcast, a VANET broadcast protocol, comprises of three components: relay-node selection, MRTS handshaking, and adaptive beacon control. The digital street map information and one-hop neighbor information are used to select relay nodes. The MRTS mechanism is applied to protect message transmissions. “Hello” beacons are used to exchange information between neighbors. Meanwhile, an adaptive beacon control heuristic is proposed to dynamically adjust the number of beacons transmitted.

As Fig. 1 shows, a RoadSide Unit (RSU) can pick up relay nodes from its one-hop neighbors and disseminate packets over specified road segments. The selected OnBoard Units (OBUs), upon receiving messages, disseminate packets in their forward directions. The selected OBUs will reply ACKs to ensure reliability.

A. Selection of Relay Nodes

In order to reduce redundancy, we apply the Multi-Point Relay (MPR) broadcast strategy [11] to reduce the number of relay nodes. Since vehicles are distributed along streets, we can simplify the selection of MPR by the assistance of the digital street map. Every OBU and RSU maintains a neighbor table. An RSU maintains a neighbor list for each road direction in its neighbor table, and an OBU only maintains two neighbor lists for forward and backward directions, respectively.

![Fig. 1. An example of Streetcast.](image)
assume that each vehicle has a GPS to provide position information. Each node in VANETs periodically broadcasts a "Hello" beacon, which includes the node’s ID, location and time stamp. When a node receives a "Hello" beacon, it checks the digital street map and updates the neighbor information to its neighbor list. A neighbor is deleted from the table if no beacons are received from it for a period of time. If there is a message needed to be broadcasted, the node with the optimal distance is picked from each neighbor list as the relay node. If transmission fails, they will not be selected as relay nodes again.

B. Multicast Request to Send

In Streetcast, we use MRTS [4] [5] to protect message from collisions. An MRTS is an one-to-many transmission handshake. With the MRTS mechanism, senders can send packets to multiple receivers simultaneously without worrying about collisions and hidden-terminal problems. According to the implementation described in [4]. An MRTS packet may be larger than a typical packet in 802.11, resulting in collisions due to hidden-terminal problems. A sender transmits an MRTS frame first and waits for CTSs from receivers. A source puts its addresses of relay nodes in the MRTS frame and multicasts it to the relay nodes. Nodes receiving the MRTS frame set their NAVs (Network Allocation Vectors) if they are not the relay nodes. Only relay nodes reply CTSs to the source following the order specified in the MRTS frame. For example, in Fig. 2, the node in Ra1 replies first, then Ra2, Ra3 and Ra4. Whenever the source gets any CTSs, it broadcasts DATA. After receiving the DATA, the relay nodes send ACKs to the source with the same order as in the transmission of CTS. The data packet size increases as there are more receivers. Jain et al. [5] modified the MRTS frame to include at most four receivers to reduce collisions and overheads. Fig. 2 illustrates the MRTS frame format. We fix the number of receiver addresses in the MRTS frame to at most four as in [5]. The transmission may fail due to loss of CTSs or ACKs. According to the number of received ACKs, a source can decide whether the transmission is successful or not, and re-initiate the MRTS procedure. If no CTS is received, the source will directly re-initiate the MRTS procedure. Fig. 3 illustrates the detail procedure.

C. Adaptive Beacon Control

In urban areas, there could be thousands of vehicles moving across intersections in short period of time, according to the statistics by the Department of Transportation, Taipei City. If each vehicle keeps sending beacons, it will cause many collisions and failures. So, we propose a beacon control mechanism to adjust beacon generation rate.

The main function of beacons in the proposed approach is to find the farthest neighbor in each direction for greedy forwarding. However, it is not necessary to let all nodes send beacons. There should be a proper number of nodes sending beacons. Consider a specified node, and assume that there are neighbors in a direction of this node. Let \( R \) denote the transmission range, \( X_1, X_2, ..., X_\alpha \) denote the distances between this node and its neighbors, and \( l \) denote the farthest neighbor distance, i.e. \( l = \max_{i=1}^\alpha X_i \). Let \( F(l) \) and \( f(l) \) be the CDF and PDF of \( l \). Then,

\[
F(l) = \Pr \left[ \text{all neighbors are not } l \text{ far apart} \right] = \Pr \left[ X_1 \leq l, X_2 \leq l, ..., X_\alpha \leq l \right] = \prod_{i=1}^\alpha \Pr [X_i \leq l] = \left( \frac{l}{R} \right)^\alpha, \tag{1}
\]

and

\[
f(l) = \frac{d}{dl} F(l) = \alpha \left( \frac{l}{R} \right)^{\alpha-1} \frac{1}{R}. \tag{2}
\]

The expected value of \( l \), denoted by \( E(l) \), is

\[
E(l) = \int_0^R l f(l) dl = \int_0^R l dF(l) \tag{3}
= l F(l)|_0^R - \int_0^R F(l) dl
= \frac{\alpha}{\alpha + 1} R.
\]

Let \( D_{opt} \) denote the preferred forwarding progress. So, the expected number of neighbors sending beacons can be calculated from \( E(l) \geq D_{opt} \). Therefore,

\[
\alpha \geq \frac{E(l)}{R - E(l)}.
\]
To adjust the beacon generation rate \( p \), a node listens the channel for a period of time and counts the number of receiving beacons before sending beacons. Let \( b \) denote the number of receiving beacons. Then,

\[
p = \Pr(b) = \begin{cases} 
\frac{1}{2\Delta}, & b \leq \alpha - \Delta \\
\alpha - \Delta \leq b \leq \alpha + \Delta \\
0, & \alpha + \Delta \leq b 
\end{cases}
\]

where \( \Delta \) is a given threshold.

IV. SIMULATION RESULTS

In order to evaluate the performance of the Streetcast, we use the GloMoSim 2.03 simulator [13], which is an event driven simulator. The vehicle mobility trace file is simulated by a separated simulator written in C according to the traffic flow collected from the Department of Transportation, Taipei city in the year 2008.

We compare the performance of random backoff flooding (denoted by RB), role-based multicast (denoted by RBM) [7], Multipoint Relays (denoted by MPR) and our Streetcast (denoted by Streetcast). We also evaluate the Streetcast without adaptive beacon control (denoted by Streetcast-nB) to validate the effectiveness of the adaptive beacon control mechanism.

Random backoff flooding and role-based multicast are flooding based mechanisms which broadcast packets without any network topology information or any neighbor knowledge. They try to reduce collisions by forcing nodes to wait for a random waiting time or base on the distance from a source before forwarding packets. For random-backoff flooding and distance based multicast, each node must rebroadcast once for the received packets. MPR is an efficient link state packet forwarding mechanism which is used in Optimized Link State Routing protocol (OLSR) [11]. MPR uses two-hop neighbor information to select multi-point relay nodes for efficient broadcast.

We use the street map of Taipei city as our map information in the simulation as shown in Fig. 4. All nodes (OBUs, RSUs) have the same transmission (and collision) range with \( r = 80m \). Two nodes can directly communicate with each other if the distance between them is less than the transmission radius \( r = 80m \). We use CBR traffic in our simulation, and the CBR data packet size is 512 bytes. The details of simulation parameters are depicted in Table I.

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>SIMULATION PARAMETERS.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicles speed</td>
<td>30km/hr 50km/hr</td>
</tr>
<tr>
<td>Transmission range</td>
<td>80m</td>
</tr>
<tr>
<td>Simulator</td>
<td>GloMoSim 2.03</td>
</tr>
<tr>
<td>Packet sizes</td>
<td>CBR 512bytes</td>
</tr>
<tr>
<td>Simulation time</td>
<td>100 s</td>
</tr>
<tr>
<td>Number of lanes</td>
<td>2 lanes per direction, 2 directions</td>
</tr>
<tr>
<td>Channel capacity</td>
<td>2 Mbps</td>
</tr>
<tr>
<td>Path loss model</td>
<td>Two-Ray</td>
</tr>
</tbody>
</table>

In accordance with the traffic flow collected from the Department of Transportation, Taipei city in the year 2008, for example, the intersection of MinQuan Rd. and ChengDer Rd. has MAX/MIN traffic flow about 9768/563 cars in 15 minutes. The average traffic flow evaluated from the statistic data is about 30cars/100meters. All cars are deployed in the map based on the Poisson distribution with random speed between 30km/hr~50km/hr and turn to different direction at intersections with equal probability. There are 9 RSUs in the simulation as depicted in Fig. 4. Each RSU periodically broadcasts packets to the specific coverage area.

We first investigate the impact of packet generation rate on the packet delivery ratio. As we expected, Streetcast has a higher delivery ratio than random backoff flooding, role-based multicast and MPRs as shown in Fig. 5. Streetcast has better delivery ratio because the MRTS protects wireless communications and selects relay nodes to reduce the redundancy and provide reliability. However, the delivery ratios for all schemes become lower as the increasing of the packet generation rate. We discuss the difference of two flooding based mechanisms. We can observe that while the packet generation rate increases, the decreasing rate of packet delivery ratio for role-based multicast is higher than random backoff flooding because of...
high node density. Almost every one hop neighbor has the same distance to the source, and broadcasts at the same time. It will lead to more serious collisions than random backoff flooding. As shown in Fig. 5, we can observe that MPRs has the lowest packet delivery ratio among the protocols. It is because that there is no mechanism to protect wireless communications in the MPR. Finally, both Streetcast protocols have high delivery ratio.

Fig. 6 illustrates the packet generation rate v.s. average collision number. We can observe that both Streetcast versions can reduce the collisions efficiently. Note that the most part of collisions in the Streetcast is caused by beacon broadcasts. Therefore, adaptive beacon control can effectively reduce the collision numbers in the Streetcast. The collisions in the flooding based protocols are caused by the excessive rebroadcasts from receivers. The reason for the collision number in MPR is comparable to Streetcast protocols is that the MPR does not have mechanisms to protect wireless communications. Therefore, the MPR has a higher collision number than both Streetcast versions.

V. CONCLUSIONS

In this paper, we proposed a broadcast protocol for VANETs, called Streetcast, which makes use of neighbor information and digital street map information. The Streetcast uses the MRTS mechanism to protect wireless communications, avoid collisions and hidden terminal problems, and enhance the reliability. The digital street map information combined with the neighbor information are used for the relay-point selection. Meanwhile, an adaptive beacon control mechanism is proposed to reduce the control redundancy. The simulation results show that for the backoff-based flooding protocols, they are useful for broadcasting data without knowing the network topology or neighbor information in a loose network, but not suitable for a high density network such as VANET. The broadcast storm problem is critical to affect the performance of these protocols. In summary, the Streetcast has superior performance than random backoff flooding, distance based multicast and MPRs in terms of packet delivery ratio and collisions under different traffic loads. In the future, we will try to use other means of MPR selection methods, e.g., velocity based grouping, instead of relying the geographic information obtained by GPS.

ACKNOWLEDGMENT

This work of Dr. Yi described in this paper was partially supported by NSC under Grant No. NSC97-2221-E-009-052-MY3 and NSC98-2218-E-009-023, by MoEA under Grant No. 98-EC-17-A-02-S2-0048, by ITRI, and by the MoE ATU plan.

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