Mobility Prediction Based Multi-Directional Broadcasting for Both Highway and Urban Vehicular Sensor Networks

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\textbf{ABSTRACT} This paper proposes a mobility prediction based multi-directional broadcasting (MPMB) protocol for both highway and urban Vehicular Sensor Networks (VSNs). VSNs have to ensure the prompt dissemination of critical sensing data to all vehicles within the Region of Interest (ROI) to avoid various road dangers. Several research studies have proposed various broadcasting protocols, but most of them just focus on either highway or urban scenarios. MPMB protocol is derived from the mobility prediction based directed broadcasting (MPDB) protocol which is a single directional broadcasting protocol for highways. The main purpose of MPMB is to improve broadcasting efficiency in both highway and urban scenarios. To do this, MPMB adopts the adaptive directional sectors and the Store-Carry-Forward (SCF) scheme to select the next broadcasting (rebroadcasting) vehicles based on the mobility prediction. MPMB protocol consists of (i) mobility prediction stage and (ii) broadcasting stage. In the mobility prediction stage, each vehicle predicts the Link Available Time (LAT) of its all neighbor vehicles through periodical beaconing. In the broadcasting stage, each broadcasting vehicle adaptively selects a vehicle with the largest LAT value predicted in the previous mobility prediction stage as a rebroadcasting vehicle in each possible directional sector. The simulation results show that MPMB protocol has better performance in terms of packet delivery rate and packet delay in comparison with three well-known reference protocols in both highway and urban scenarios with various traffic density.

\textbf{INDEX TERMS} Emergency message dissemination, mobility prediction, multi-directional broadcasting, vehicular sensor networks, intelligent transportation.

\section{I. INTRODUCTION}
Vehicular Sensor Networks (VSNs) have been spotlighting for road safety, traffic efficiency, and data services in the vehicular road networks and Intelligent Transportation Systems (ITS) [1]–[3]. A VSN comprises of a large number of vehicle sensors and is required to disseminate critical sensing data in real-time to all vehicles in the region of interest to avoid various road hazards. These sensing data can also be used as effective information to provide a variety of services for future ITS and smart cities [4], and various service recommendations are being actively studied [5]–[10]. A VSN is a subclass of Vehicular Ad Hoc Network (VANET) which is the most important component of ITS. In ITS, traffic, weather, and charging facilities [11] information, road hazard and obstacle information, and traffic accidents are usually disseminated by broadcasting protocol. Therefore, the various significant sensing data gathered by the different types of sensors should be disseminated to all neighbor vehicles to prevent secondary accidents. Broadcasting is considered as the most suitable communication mechanism to disseminate the safety message in VSNs. Broadcasting is the message dissemination process in which a source vehicle sends a message to all other neighbor vehicles in VSNs. If a traffic accident happens on a road, then the emergency message should be broadcasted to all vehicles in Region of Interest (ROI) [12] which is the area exposed to potential hazards. In VSNs, emergency messages have to be disseminated without any time delay to avoid potential accidents [13]–[20]. If some neighbor vehicles don’t receive the emergency message because of message collision or transmission error [21], they may be exposed to secondary accidents. To resolve these problems,
many research works are proposed in VANETs [22]–[24]. A common way of transmitting emergency messages to neighbors is to use well-known communication protocols such as universal mobile accessibility (Wi-Fi hotspots and cellular networks. However, such protocols are not suitable for the transmitting due to their characteristics (connecting session between vehicle nodes and using unicasting in data exchange). In VSN, emergency messages should be immediately transmitted to neighbors. According to broadcasting and rebroadcasting are widely used in the research works.

The simplest broadcasting method is flooding [25] that allows all vehicles to transmit the messages [26]. In dense networks, flooding schemes cause broadcast storm problems [27], [28], which include excessive message redundancy, media contention, and message collision. Selective flooding can overcome the broadcast storm problems through the selection of relay vehicles that rebroadcast the messages. Nevertheless, selective flooding schemes cannot provide enough reliability for the emergency message dissemination because of highly dynamic topology change resulting from the fast movement of vehicles. In sparse networks, network disconnections arise when there is not any vehicle in the direction of interest. In such cases, selective flooding schemes should apply a Store-Carry-Forward (SCF) mechanism [29] to store and relay the messages until the time there is a new vehicle for disseminating the messages.

In this paper, we propose a mobility prediction based multi-directional broadcasting (MPMB) protocol that can support both highway and urban scenarios for VSNs. The MPMB is expanded by improving our mobility prediction-based directed broadcasting (MPDB) protocol [30] which is a one-directional broadcasting protocol. Therefore, the MPDB is especially useful for highway roads. However, the proposed MPMB protocol fulfills the multi-directional broadcasting for both highway and urban scenarios in VSNs. MPMB adopts the adaptive directional sectors, the mobility prediction, and the SCF scheme to select the next broadcasting (rebroadcasting) vehicles in each possible directional sector. Similar to the MPDB protocol, MPMB protocol also consists of two stages: the mobility prediction stage and the broadcasting stage. However, unlike the MPDB protocol, the Link Available Time (LAT) calculation is conducted in the mobility prediction stage of the MPMB protocol. In the mobility prediction stage, each vehicle predicts the LAT of its all neighbor vehicles through periodical beaconing. In the broadcasting stage, each broadcasting vehicle adaptively selects just one vehicle with the largest LAT value predicted in the previous mobility prediction stage as a rebroadcasting vehicle in each directional sector. And the broadcasting stage broadcasts the message containing the rebroadcasting vehicle ID for each possible directional sector to all directional neighbor vehicles. MPMB protocol can reduce the unnecessary delay caused by the media contention between neighbor vehicles because which vehicle has to rebroadcast the message is decided by their previous hop. MPMB protocol also can improve the reliability in both highway and urban areas by adopting the adaptive directional sectors, the mobility prediction, and the SCF scheme.

The remainder of this paper is organized as follows. In Section 2, we describe a summary of the state-of-the-art in broadcasting protocols for vehicular networks and review the literature and outline problems of them. Section 3 presents MPMB protocol and where we elaborate on detailed protocol design principles, packet format, and mobility prediction mechanisms and broadcasting algorithms of MPMB protocol. In Section 4, the performance of MPMB protocol is evaluated by applying both realistic highway and urban scenarios. Finally, in Section 5, we describe the conclusions of MPMB protocol and present future works.

II. RELATED WORK
In the past decade, many kinds of research in academia and industries have been working to improve routing protocols for vehicular ad hoc networks (VANETs). In such works, most protocols have tried to resolve well-known problems including redundant transmission, broadcast storm, and frequently change of topologies in various environments (i.e., urban, suburban, and highway) [31]–[33]. In this section, we investigate and analyze the existing routing protocols for VANET and describe the need for more advanced broadcasting protocols.

Ohta et al. proposed a new reliable data forwarding scheme to resolve duplicated data packets in the Store-Carry-Forward (SCF) [34]. To this end, they combined the Epidemic routing [35] and vehicle information which is composed of position information and moving direction of each vehicle node derived from its Global Positioning System (GPS). Furthermore, they defined two conditions based on the vehicle information to determine to select the next node for forwarding data packets. Consequently, they enable to reduce duplicated data packets when vehicle node forward data packets to neighbor nodes.

Korkmaz et al. proposed a new efficient IEEE 802.11 based urban multi-broadcasting protocol (UMB) to resolve multi-hop broadcasting problems in vehicular ad hoc networks [36]. In particular, they try to resolve broadcast storms, hidden nodes, and reliability. To this end, they proposed two main broadcasting methods which are directional broadcast and intersection broadcast. In the directional broadcast method, they use the Request to Broadcast (RTB) and Clear to Broadcast (CTB) to avoid the hidden node problem. In the intersection broadcast method, they also use repeaters located at an intersection to select the best candidate becomes the next node for forwarding data packets to the destination. Consequently, the proposed protocol showed higher performance comparing with other 802.11-based protocols for VANET. However, these research works do not consider the mobility prediction of nodes. In VANET, the mobility of nodes is very important because it would affect the changing of topologies.

Yuanguo et al. proposed a multi-hop broadcast protocol, which could be called Urban Multi-hop Broadcast
Protocol (UMB) to improve emergency message dissemination in urban scenarios of VANET [37]. To this end, they used three broadcast strategies such as bi-directional broadcast, multi-directional broadcast, and directional broadcast to select next relay nodes which have the role for forwarding message to other nodes or destination. Besides, they proposed a node selection scheme to quickly select a remote neighboring node by utilizing iterative partition, mini-slot, black-burst, and asynchronous contention mechanisms. Consequently, they showed the performance of UMB regarding packet delay and propagation speed according to several vehicle nodes. Although the proposed protocol resolves quick selection node problem and broadcast storm problem, they cannot consider a number of the direction of moving vehicles in practice. Furthermore, they also cannot consider highway scenarios in VANET. For highway scenarios, we should consider empty neighbor nodes (e.g., lowest density node in transmission range) and link breakage according to different velocity between vehicle nodes due to the characteristics of VANET.

Sun et al. proposed a new broadcasting protocol to reduce waste bandwidth in inter-vehicle communication (IVC) [38]. In particular, they tried to resolve the disadvantage of the existing table-driven protocol. To this end, they proposed two approaches called the Vector-based TRAcking DEtection (V-TRADE) and History-enhanced V-TRADE (HV-TRADE), respectively. In the V-TRADE, they make use of three vectors to classify the neighborhood of the sender node, and then it classifies the nodes into five groups using a heuristic approach. In the HV-TRADE, each node maintains a position history including the vehicle’s previous position within the transmission range. Finally, they incorporated HV-TRADE approach into V-TRADE. Consequently, they could reduce the bandwidth required for message broadcast through the above two approaches. Although they can reduce the bandwidth using the position of nodes including moving history, they do not consider node density in the IVC. Furthermore, this research work requires bags of time for a heuristic approach.

Tonguz et al. proposed a distributed vehicular broadcast protocol (DV-CAST) for VANET [39]. In the research work, they designed a distributed broadcast protocol to both mitigate the broadcast storm and maintain network connectivity in disconnected networks. The proposed protocol is composed of three major components which are neighbor detection, broadcast suppression, and store-carry-forward mechanisms. Each component is used to estimate a local topology by monitoring neighbors, to hand broadcast storm problem in a dense traffic regime, and to maintain connectivity in a sparse network. Also, they used the region of interest (ROI) to resolve two opposite directions on the highway when a sender node forwarding data packets to the next node. Accordingly, the proposed network showed higher performance in terms of reliability, efficiency, and scalability than existing broadcasting protocols in highways under multiple traffic conditions. However, the proposed protocol only considers one-hop neighbors and highway scenarios in VANETs.

Viriyasitavat et al. proposed a broadcasting routing protocol, which could be called Urban Vehicular BroadcastCAST (UV-CAST) for urban VANETs [40]. The proposed protocol is designed to support both network conditions which are disconnected and well-connected networks in urban scenarios. Each vehicle, therefore, can communicate with each other in zero infrastructure support. For this mechanism, the protocol uses a store-carry-forward (SCF) mechanism to support the disconnected network. And also, the protocol would avoid redundant messages generated by rebroadcasting using periodic hello messages. Consequently, the protocol shown higher performance than other similar protocols in terms of reachability, received distance, and network overhead in urban scenarios.

Ros et al. proposed an adaptive broadcast protocol, called Acknowledged Broadcast from Static to highly Mobile (ABSM) which is a localized broadcast protocol for VANETs [41]. The ABSM working on the DS-NES framework in existing delay-tolerant networks. For this framework, the ABSM uses a connected dominating set (CDS) [42] and neighbor elimination scheme (NES) [43] based on one-hop neighborhood position information acquired from periodic beacons. Accordingly, the ABSM would improve protocol reliability and efficiency in a vehicular environment. However, the proposed ABSM could not cover safety applications because it does not consider delay constraints regarding retransmission time-out.

Chaqfhe et al. proposed the efficient multi-directional data dissemination protocol (EDDP) to consider the requirements of an urban vehicular environment [44]. The proposed protocol offers multi-directional broadcast mitigation in a multi-hop manner. To do this, they design urban layout including the message format, a broadcast suppression mechanism, and delay control. In particular, they used a delay-based data dissemination method using total timeslots to avoid broadcast storms and packet collisions in urban vehicular scenarios. However, they cannot consider diverse road types including several way intersections. Furthermore, the protocol only considers urban vehicle scenarios without highway scenarios.

Ko et al. proposed an algorithm named RSU Cooperation-based Adaptive Scheduling (RCAS) which consists of three mechanisms centralized scheduling mechanism, ad hoc scheduling mechanism for vehicles, and cluster management mechanism to dissemination data in a vehicular environment [45]. In this algorithm, the centralized scheduling mechanism used for RSU’s coverage to disseminate data using cooperative I2V and V2V. On the other hand, the ad hoc scheduling mechanism is exploited to share cached data via V2V based on the dynamic construction of clusters in out of RSU’s coverage. Finally, the proposed algorithm resolves problems of RSU coverage according to the location of vehicles. Although they resolve problem link breakage out of RSU’s coverage according to the location of vehicles,
they cannot consider moving directions of vehicles and differences of vehicle density in-vehicle environments both urban and highway.

Nawaz et al. presented an experimental implementation based on visible light communication (VLC) for the vehicular environment [46]. To this end, they developed a testbed for VLC including small infrastructure (i.e., traffic light), photodetector, RX decoder, and TX encoder. And then, they showed results of PER and PER broadcast performance. Consequently, they showed the feasibility of VLC via the experimental implementation. VLC is one of the key technologies to realize ITS. However, we still do not have the infrastructure for VLC in practice. Thus, if we have the infrastructure in practice, the VLC would be a core technology with existing research works including our proposed solution.

As described in this section, many research works have been trying to improve existing broadcasting efficiency in vehicular environments. To improve broadcasting in the environments, we should consider to efficiently select the next broadcasting (rebroadcasting) vehicle nodes based on the mobility prediction with multi-direction of the node. From this perspective, we propose a mobility prediction based multi-directional broadcasting (MPMB) protocol.

III. MOBILITY PREDICTION BASED MULTI-DIRECTIONAL BROADCASTING

A. PROTOCOL DESIGN PRINCIPLE

1) REGION OF INTEREST (ROI)

In this section, we illustrate the different Region of Interest (ROI) to meet a reliable message broadcasting in real-time between the one-dimensional highway and two-dimensional urban areas. The appropriate selection of ROI for emergency message dissemination is determined differently according to required scenarios such as highway and urban areas as shown in Figure 1. As shown in Figure 1(b), the emergency message in the ROI for urban scenarios has to be disseminated multiple directions, such as North, South, East, West because there are many intersections and the possible direction changes of vehicles at intersections. The message dissemination for highway scenarios may not work in the ROI for urban scenarios. And the Store-Carry-Forward (SCF) mechanism used in highway scenarios might not be an appropriate solution for urban areas because urban areas have many traffic lights and they generate frequently a network disconnection. Therefore, the broadcasting protocols for urban scenarios can disseminate the message all (or multiple) directions in the ROI and more than one vehicle has to be incorporated in the SCF task. The multiple SCF assigned vehicles may cause redundant rebroadcasting messages. It is a solution to prevent redundant messages to restrict only when the SCF assigned vehicles to receive a beacon message from the new neighbor vehicle.

2) ADAPTIVE DIRECTIONAL SECTOR

MPMB protocol adopts the directional sector scheme to adaptively disseminate the emergency message to multiple directions according to the type of road based on the ROI described in Sector 3.1.1. The directional sectors of a vehicle are defined as the geographical group of vehicles within the vehicle’s transmission range. The maximum direction is restricted by eight in which a directional sector has the 45-degree range. This is because if the moving direction of two vehicles is less than 45 degrees, they are considered to be moving the same direction. In MPMB protocol, a broadcasting vehicle only selects one vehicle with the largest LAT among neighbor vehicles as the next broadcasting vehicle in each directional sector by predicting their mobility through periodical beaconing. MPMB protocol works seamlessly in both highway and urban scenarios through the adaptive selection of the directional sector. The directional sector is selected from one direction to eight directions according to the road topology information obtained from the digital road map.

Figure 2 and Figure 3 show some examples of how the adaptive directional sectors are applied in highway and urban scenarios.

In highway scenarios, MPMB protocol selects from one direction sector to three direction sectors according to the type of highway road. As shown in Figure 1a, the dissemination direction of the emergency message for highways is restricted to just behind vehicles following a message disseminator. Therefore, MPMB protocol can adopt one direction sector, d1 as shown in Figure 2a in the case of a typical straight highway. However, MPMB protocol can adopt the maximum of three direction sectors in highway scenarios. In Figure 2b, MPMB protocol just selects three sectors, d1, d2, and d8 according to the type of highway road. This is because the sectors d1, d2, and d8 are just behind sectors of the source vehicle, V1.
Whereas in urban scenarios, MPMB protocol selects one of two-direction, four-direction, or eight-direction according to the urban road topology to disseminate the emergency message to all possible directions in the ROI for urban as shown in Figure 3. For instance, the Manhattan street topology would have two, four, and more possible directions in a region comprising an intersection.

**B. PROTOCOL DESIGN**

1) **ASSUMPTIONS AND BEACON FORMAT**

Similar to other broadcasting protocols, we assume all vehicles in MPMB protocol are equipped with wireless communication, computation, and storage capabilities. We also assume all vehicles to be equipped with a Global Positioning System (GPS) receiver to obtain their position data. Each vehicle has a unique ID and is distinguished from each other by the ID. The MPMB protocol uses the digital road map by the GPS navigation system to adaptively disseminate each message to multiple directional sectors.

In MPMB, each vehicle exchanges the up-to-date status of neighbor vehicles within its transmission range through periodical beaconing. The beacon message format is defined as shown in Figure 4. Based on the periodical beaconing, each vehicle maintains its neighbor table. The beacon message informs other neighbor vehicles to estimate the future position and the LAT of the vehicles within a single-hop in their neighbor tables.

In Figure 4, the beacon message contains the identity, position, velocity, and direction of a vehicle when the message is generated. Then, the receiver vehicle can predict the neighbor vehicles’ mobility information, such as the relative speed, the relative moving direction, the inter-vehicle distance, and the LAT.

The neighbor information table is designed to support MPMB protocol with the following data structure maintained in each vehicle: ID, Position, Speed, Direction, Distance, LAT, Selection. Essentially, the neighbor vehicle’s position information, the predicted relative speed, the relative moving direction, the predicted inter-vehicle distance can be acquired through beacon message exchanging. Table 1 shows an example of the neighbor information table of vehicle 1 (V1).

In Table 1, ID is the vehicle identity, and the position of the vehicle is the GPS coordinates, (x, y). The selection value indicates which vehicles are selected as the next broadcast vehicle. The value 1 means being selected vehicles and 0 means not selected vehicles.

2) **MOBILITY PREDICTION**

In this work, we consider the multi-directional broadcasting for both highway and urban scenarios through the mobility prediction of moving vehicles. Table 2 defines the symbols used in the mobility prediction equations.

The Relative moving direction ($\Delta \theta$) is calculated by (1).

$$
\Delta \theta = \begin{cases} 
\frac{y_i + \Delta t - y_i}{1E - 6} \times \frac{180}{\pi}, & x_i + \Delta t = x_i \\
\frac{y_i + \Delta t - y_i}{x_i + \Delta t - x_i} \times \frac{180}{\pi} + 180, & x_i + \Delta t < x_i \\
\frac{y_i + \Delta t - y_i}{x_i + \Delta t - x_i} \times \frac{180}{\pi} + , & \text{otherwise}
\end{cases}
$$

(1)
The speed $v_i$ and direction $\theta_i$ of vehicle $i$ during each time are distributed over the ranges of $(0, v_{\text{max}})$ and $(0, 2\pi)$, respectively. When a beaconing time starts, the current position of vehicle $i$ is $(x_i, y_i)$ and the current distance between vehicles $i$ and $j$ is $d_{ij}$. After the beaconing time $t$, the position of vehicle $i$ can be calculated as (2). And also, the predicted link available time (LAT) between vehicles $i$ and $j$ is obtained by (3).

\[
x_i + \Delta t = x_i + v_i \cos \theta_i, \quad y_i + \Delta t = y_i + v_i \sin \theta_i \tag{2}
\]

\[
LAT_{ij} = \left\{ \begin{array}{ll}
-(\delta dx' + \xi dy') + \sqrt{\Delta v_{ij}' R^2 - (\delta dx' + \xi dy')^2} / \Delta v_{ij}' & , \Delta v_{ij}' \neq 0 \\
T_b \times 2, & , \Delta v_{ij}' = 0
\end{array} \right.
\tag{3}
\]

\[
\Delta v_{ij}' = \delta^2 + \xi^2 \tag{4}
\]

\[
\delta = v_i \cos \theta_i - v_j \cos \theta_j \tag{5}
\]

\[
\xi = v_i \sin \theta_i - v_j \sin \theta_j \tag{6}
\]

\[
dx_i' = dx_i + v_i \cos \theta_i - x_j + v_j \cos \theta_j
\]

\[
dy_i' = dy_i + v_i \sin \theta_i - y_j + v_j \sin \theta_j \tag{7}
\]

Consequently, the distance $d_{ij}'$ after time period $t$ can be expressed as (8).

\[
d_{ij}' = \sqrt{\alpha t^2 + \beta t^2 + d_{ij}^2} \tag{8}
\]

\[
\alpha = v_i^2 + v_j^2 - 2v_i v_j \cos (\theta_i - \theta_j) \tag{9}
\]

\[
\beta = 2\delta (x_i - x_j) + 2\xi (y_i - y_j) \tag{10}
\]

\[
d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{11}
\]

C. ALGORITHMS

In this section, we explain the algorithms of MPMB protocol which is composed of two stages: a mobility prediction stage and a broadcasting stage. In the mobility prediction stage, each vehicle predicts the LAT of its all neighbor vehicles through periodical beaconing. In the broadcasting stage, MPMB selects the next broadcasting (rebroadcasting) vehicles using the LAT values calculated in the mobility prediction stage, and the direction sectors based on the ROI corresponding to where the cars are on the road. Each algorithm has $O(n)$ time complexity so that the proposed algorithm enables us to quickly compute and select the next vehicle nodes. Table 3 defines the symbols used in our algorithms.

| Symbols | Definitions |
|---------|-------------|
| $s$ | Moving direction |
| $\Delta s$ | Relative moving direction |
| $v$ | Vehicle speed |
| $\Delta v$ | Predicted relative speed |
| $\Delta t$ | Time after beacon time $\Delta b$ |
| $\delta$ | Directional cosine of the angles between two vehicles |
| $\xi$ | Directional sine of the angles between two vehicles |
| $R$ | Transmission radius |
| $d_{ij}'$ | Predicted inter-vehicle distance |

TABLE 3. Definition of symbols used in the algorithms of MPMB.

| Symbols | Definitions |
|---------|-------------|
| $V_S$ | Sender vehicle |
| $N$ | A set of neighbors within $V_S$'s transmission range |
| BM | Broadcast message |
| $S_{\Phi}$ | Sets calculated from ROI |
| RBV | Rebroadcasting vehicles |
| $S_r$ | Selection value |
| $B$ | Beaconing message |
| $\Delta b$ | Beaconing time |
| $N(i)$ | The number of $i$ |
| $NIT_i$ | The neighbor information table of vehicle $i$ |
| $TR_i$ | Transmission range of vehicle $i$ |

Algorithm 1 Mobility Prediction Process

Input: $(x, y), \theta, v, t$

Output: $(x + \Delta t, y + \Delta t), \Delta \theta, \Delta v, LAT, NIT$

1. $V_S$ sends $B$ to $N$ every $\Delta b$
2. If $N(N) \neq \Phi$ then
3. For $i = 1: N(N)$
4. $V_S$ calculates $(x + \Delta t, y + \Delta t), \Delta \theta, \Delta v$
5. $V_S$ calculates $LAT$
6. $V_S$ updates $NIT$
7. End for
8. End if

1) MOBILITY PREDICTION ALGORITHM

The method of mobility prediction is used to find out the LAT values about neighbor vehicles through periodical beaconing. The beacon message used here is shown in Figure 4.

Algorithm 1 describes the mobility prediction algorithm for MPMB protocol.

The mobility prediction algorithm uses neighbors’ position ($(x, y)$), speed $(v)$, direction $(\theta)$, and time $(t)$ as its inputs and makes a prediction about neighbor’s position ($(x + \Delta t, y + \Delta t)$) after some time $(\Delta t)$, relative moving speed $(\Delta v)$, moving direction $(\Delta \theta)$ every its beaconing cycle by using the formulas described in the preceding section. Eventually, when these values are predicted, the mobility prediction algorithm can find out the LAT values of all neighbor vehicles and update them on the neighbor information table ($NIT$).

2) BROADCASTING ALGORITHM

The broadcasting algorithm of MPMB protocol is shown in Algorithm 2.

In the broadcasting stage, MPMB protocol selects only one vehicle with the largest LAT value as a rebroadcast vehicle.
Algorithm 2 Broadcasting Process

Input: \( ROI \), LAT, NIT

Output: RBV, NIT

1. If \( V_S \) has or receives BM then
2. While TTL \( \neq 0 \)
3. \( V_S \) detects \( S_{ROI} \) from ROI
4. For \( i = 1: N(S_{ROI}) \)
5. If \((x_i, y_i) \in S_{ROI} \) \&\& \( d_{is} < TR_s \)
6. \( \{x|S_{ROI}\} \leftarrow i \)
7. End if
8. End for
9. If \( \forall \{x|S_{ROI}\} = \Phi \) then
10. do SCF
11. Else
12. For \( i = 1: N(\{x|S_{ROI}\}) \)
13. If \( \{x|S_{ROI}\} = \Phi \) then
14. do SCF
15. Else
16. \( RBV_{N(i)} = \arg \max \text{LAT}_{N(i)} \)
17. \( RBV_{N(i)} \) set \( S_V \) to 1
18. \( V_S \) broadcasts BM with \( RBV_{N(i)} \)
19. End if
20. \( V_S \) updates NIT\( s \)
21. End if
22. End while
23. End if

among each sector to which the neighbors belong in by using the ROI and a digital map. In MPMB protocol, the LAT values for neighbor vehicles are previously calculated in the previous stage, the mobility prediction algorithm. In other words, the broadcasting stage of MPMB protocol doesn’t calculate the LAT values for finding the next broadcasting vehicles. Therefore, when urgent message propagation is required, MPMB protocol can deliver the message immediately without any competition or conflict using the LAT values already obtained in the previous stage.

The broadcasting process of MPMB protocol basically follows the SCF scheme. MPMB protocol just allows the selected rebroadcast vehicles (RBV) for each sector \((S_{ROI})\) to rebroadcast the broadcast message (BM). The selected RBV are those with the largest LAT values within the same sector. If vehicles have a BM or are received a BM from other vehicles, they detect their valid sectors \((S_{ROI})\) from the ROI and a digital map and constitute their set of sectors \((\{x|S_{ROI}\}\)} in their neighbor vehicles. If there are no valid sectors, MPMB runs the SCM scheme to keep and deliver until a valid sector is found. The MPMB also does the SCM scheme for sectors with no vehicles among several valid sectors. If more than one vehicle exists within the same sector, MPMB selects the vehicle with the largest LAT value as the RBV and sets the selection value \((S_V)\) of the RBV to 1. Therefore, only RBV with their \( S_V \) value set to 1 can rebroadcast the BM without any delay caused by the contention between neighbor vehicles. The other vehicles just drop the BM without any rebroadcasting. This process is repeated until the end of the TTL of the original BM.

IV. PERFORMANCE EVALUATION

In this section, we present simulation results obtained for both highway and urban scenarios. Furthermore, we discuss and analyze and compare the results of the proposed MPMB, MPDB, UMB, SCF, EDDP, and RCAS by using the ns-2 simulator. The main conclusion from the simulation is that the proposed MPMB can offer lower packet delay as well as better packet delivery than the others in both highway and urban scenarios. Parameters used in the simulation scenarios are shown in Table 4.

The number of vehicles is increased from 10 to 100 and the moving velocity of the vehicles is also increased from 20km/h to 80km/h (i.e., urban) or 100km/h (i.e., highway) defined as randomly. Finally, each simulation is performed during 200sec. The simulation is performed twice and average values were used. The maximum and minimum values were excluded.

A. HIGHWAY SCENARIOS

Figure 5 shows the packet delivery rate and packet delay according to the increasing number of vehicle nodes from 10 to 100 in highway scenarios. Figure 5-(a) compares the packet delivery rate of MPMB, MPDB, UMB, SCF, EDDP, and RCAS according to the increasing number of vehicles. As shown in Figure 5-(a), we found that all of the protocols have a similar packet delivery rate until 60 vehicles. This is because sender nodes of all protocols can easily select next vehicles without iterative calculation for selecting the next vehicles due to low collision when the sender transmits data packets to neighbors. In other words, the performance of all protocols is increased in 60 vehicles. However, the packet delivery rate of SCF protocol rapidly is decreased from over 60 vehicles. This is because SCF cannot select approximate next vehicle when the density of vehicles is increased. In SCF protocol, it carries data when the sender node cannot select the next node to transmit data to others. Accordingly, the SCF protocol performed iterative carry method because it cannot find the next vehicle by higher node density in this simulation. In the case of EDDP, it has a similar mechanism as SCF when the protocol forward data packet to others.

Table 4. Simulation parameters.

| Parameter          | Value                        |
|--------------------|------------------------------|
| Topology size      | 4000m * 4000m                |
| Transmission range | 250m                         |
| Number of lanes    | 4 to 8                       |
| Number of vehicles | 10 to 100                    |
| Velocity (highway) | 20km/h to 80km/h (urban) or 100km/h (highway) |
| Packet size        | 512bytes                     |
| Bandwidth          | 2Mpbs                        |
| Simulation time    | 200sec                       |

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However, unlike SCF, the EDDP computes the number of timeslots and extracts traffic status. Based on the mechanism of the EDDP, it performs forwarding data corresponding to scheduled broadcast. Although the EDDP has the lowest packet delivery rate until 60 vehicle nodes, the performance is increased over 60 vehicle nodes.

In the case of RCAS, it shows even performance according to the increasing number of vehicles. This is because the RCAS uses three types of schedules as mentioned in Section 2 which control disseminated coverage of data using cooperative I2V and V2V. Therefore the RCAS shows even performance in the simulation.

In the case of UMB and MPDB, they show similar performance. It is thought to be because UMB selects more than one next relay vehicle to reduce packet loss. However, UMB does not consider inter-vehicle link disconnection when sending messages to neighbors. In other words, the relative velocity of all vehicles on the highway has a higher gap due to its difference velocity between vehicles. Hence, link disconnection between vehicles frequently occurs on the highway. Consequently, the UMB designed for the urban has higher link breakage than the proposed MPDB. The MPDB performs mobility predictions in almost the same way as MPMB in highway scenarios. However, MPDB has shown a bit decrease in the packet delivery rate compared to MPMB because MPDB only selects relay vehicles in the rear of vehicles located within a 45-degree angle. The MPMB uses multiple sectors and ROIs to dynamically react to the structure of roads. Therefore, MPMB can offer better performance in terms of the packet delivery rate than other protocols.

Figure 5-(b) shows the packet delay of MPMB, MPDB, UMB, SCF, EDDP, and RCAS according to the increasing number of vehicles. As shown in Figure 5-(b), the SCF, EDDP, and RCAS have similar packet delay until 60 vehicle nodes. In them, the SCF shows the highest packet delay rate than the SCF and EDDP. In particular, its packet delay is increased rapidly in environments with more than 60 vehicles. This is because the broadcasting storm problem is occurred according to increasing node density. Furthermore, the relay nodes of the SCF protocol are cannot easily select the next node in the process of transmission due to iterative use of the carrying method as motioned before. In the case of the EDDP, it has a higher performance better than the SCF. Although the EDDP selects next broadcasting nodes without broadcasting storm, due to the broadcast suppression of EDDP, it might be discarded message when the vehicle nodes are increased. In contradistinction to SCF and EDDP, the RCAS has decrease packet delivery rate after 60 vehicle nodes. This is because the ad-hoc scheduling mechanism of RCAS might be used to use V2V according to the increasing density of vehicle nodes.

Both the UMB and MPDB show a similar packet delay rate. This is because both protocols resolved broadcasting storm according to increasing node density. Therefore, they have low packet delay in higher density. However, we know that the MPMB protocol has the lowest packet delay in this simulation. This is because the MPMB performs the mobility prediction as well as prevention of occurring broadcasting storm before it needs to broadcast packets. Consequently, the MPMB can deliver packets immediately without any competition or conflict.

B. URBAN SCENARIOS

For the urban scenarios, we use the real map of YongSan-gu districts in Seoul. The map is composed of 4-8 lanes, 4-way intersections and 5-way intersections, and many traffic signals. Figure 6 shows the packet delivery rate and packet delay according to the increasing number of vehicles from 10 to 100 in urban scenarios.

In Figure 6-(a), MPMB shows a higher packet delivery rate than the other protocols. The reason why MPMB uses multi-directional sectors when it forwards messages to other vehicles. In the case of the other protocols, the plot shows similar packet delivery in the urban scenarios. This is because they don’t consider the type of roads such as intersections and curves. More detail, the protocols excepting UMB protocol (i.e., MPDB, SCF, EDDP, and RCAS) are focus on the method for transmitting a data packet to neighbors. Although MPDB performs mobility prediction before broadcasting data, it only considers
highway scenarios. In the case of UMB, it considers urban scenarios via redundant data packet and preventing broadcast storm. However, the protocol also cannot consider the various type of roads and their considerations. Therefore, when they send packets to neighbors, the link breaks occur frequently. In the case of EDDP, the consider urban scenarios. Furthermore, it considers traffic status to optimal disseminate data packet to others. However, they also can not consider various road types in urban scenarios. Hence, the EDDP frequently discard message due to AOE (i.e., Area of Interest). In case of RCAS, they use RSU when the forwarding data packet to others. Therefore, the RCAS shows even performance without the number of vehicle nodes.

On the other hands, MPMB has 8-sector angles regarding multi-directions, so that it can select correct next broadcasting vehicles. Consequently, MPMB reduces packet loss irrespective of vehicle density. In the case of MPDB, it has lower packet delivery than MPMB. The reason that MPDB protocol cannot send packets in multi-directions because it was designed only just for highway scenarios. Accordingly, the MPDB protocol just can forward messages only to behind neighbor vehicles moving in the same direction.

Figure 6-(b) shows packet delay. As shown in Figure 6-(b) the protocols (i.e., EDDP and UMB) for Urban has lower packet delay. In the case of EDDP, it shows a lower packet delay until 60 vehicle nodes. And then After 60 vehicle nodes, the delay of EDDP is increased. This is because it performed according to sending a message schedule. Accordingly, when the vehicle nodes are increased, the message might be discarded by broadcast suppression. On the other hand, UMB has lower and lower performance according to the increasing number of vehicles. This is because the UMB can more easily select the next vehicle node when the vehicle node is increased.

The MPMB protocol shows lower packet delay than the other protocols. The MPMB protocol calculates moving velocity between sender vehicles and next broadcasting vehicles, and multi-direction sectors based on corresponding ROIs. Therefore, it can correctly select the next vehicles irrespective of intersections and lanes. Consequently, MPMB remarkably reduces packet delay rather than other protocols as shown in Figure 6-(b). On the other hand, MPDB has a higher packet delay compared with MPMB. The reason is that MPDB only performs mobility prediction in the rear of vehicles on highways. Therefore, MPDB cannot select correct vehicles in multiple intersection areas as tested in urban scenarios.

V. DISCUSSION

In this paper, we proposed a broadcasting protocol to improve the delivery reliability of both highway and urban VSNs. We developed algorithms that can be applied in both highway and urban scenarios. However, there are remaining issues in practice.

In-vehicle infotainment systems, such as Google Auto and CarPlay, use several communications, including short-range wireless communication (Bluetooth) and universal mobile accessibility (Wi-Fi hotspots and cellular networks). Hence, the transmission range is reduced due to signal attenuation. As mentioned above, the proposed MPMB uses the LAT to select the next broadcasting vehicles. Accordingly, the signal attenuation would influence the process of selecting the next broadcasting vehicles. Consequently, the proposed MPMB can frequently try the process of selecting the next node, and then it can affect the performance of the algorithm. Therefore, we have to consider an efficient way to improve the signal attenuation in practice.

Another issue is that road environments have various road types including curves, straights, and intersections. In particular, each road type has a different number of lanes. Although the proposed MPMB calculates multi-direction based on 8-sectors when it forwards messages to others, the algorithm cannot consider some curve type. In other words, when a vehicle is moving, it can face various road types and even the types connected. Accordingly, the results of directions calculated in our algorithm would be changed when a vehicle faces very unusual curved roads. Therefore, the prediction method is required to correctly select the next broadcasting vehicles for the environment, including roads of various shapes. That is also a challenge for us to work on.
From the perspective of VANET applications, message transmissions must be timely and reliable. Although we proposed the method of message transmission in this paper, we cannot consider the various type of applications. In particular, we focus on the propagation of emergence message. In VANET scenarios, there exist various applications including safety for the driver, intelligence services, and security services (e.g., payments). Therefore, methods that consider the characteristics of various application scenarios in VANET are also a challenging task.

Finally, we have assumed all of the vehicles have their unique ID in our scenarios. However, VSN is a network in which vehicles make up their network by themselves, and there is no way of assigning and managing ID shared by all vehicles throughout. Therefore, it is also a challenge for us to assign and manage common ID for every vehicle in VSNs.

VI. CONCLUSION
VSNs can play an important role in ensuring real-time communication and road safety for intelligent transportation. In this paper, we have developed a mobility prediction based multi-directional broadcasting (MPMB) protocol for VSNs. The MPMB comprises two stages, a mobility prediction stage, which predicts the Link Available Time (LAT) of all the neighbor vehicles, and a broadcasting stage, which adaptively selects a vehicle with the largest LAT value predicted in the previous mobility prediction stage as a rebroadcasting vehicle each possible directional sector. We performed simulations with three well-known reference protocols including the SCF, UMB, and MPDB to prove the superiority of MPMB. The simulation results revealed that MPMB could provide high packet delivery rate and low packet delay in both highway and urban scenarios. Therefore, MPMB can eventually contribute to improving the reliability of VSNs. Although we addressed advantages with its higher performance comparing with well-known other protocols, there are still remain practical issues as mentioned in Section 5. In such issues, we think that the way of assigning and managing ID shared by all vehicles throughout is the most important challenge than other issues. Thus, we will study the way to assign and manage ID.

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