A Novel Architecture for Vehicular Traffic Control

Chandan Ratnani
Dept. of Electro. & Communication
Sankalchand Patel College of Engg.
Visnagar, India
chandan.ratnani@yahoo.co.in

V. B. Vaghela
Dept. of Electro. & Communication
Sankalchand Patel College of Engg.
Visnagar, India
vanaraj79548@yahoo.co.in

D. J. Shah
Director, Samarth Group of Colleges
Himmatnagar, India
djshah99@yahoo.co.in

***Abstract*—Vehicular ad hoc network (VANET) communication has recently become an increasingly popular research topic in the area of wireless networking as well as the automotive industries. Recent advances in vehicular communications make it possible to realize Vehicular Sensor Networks (VSN) where mobile vehicles are equipped with sensors of different nature which can sense events, process sensed data and route messages to other vehicles. The goal of VANET research is to develop a vehicular communication system to enable quick and cost-efficient distribution of data for the benefit of passengers' safety and comfort. VANETs are not just for fun, their aim is even to avoid accidents using periodic broadcast of messages containing vehicles' status information such as position and speed vector and a safety system aware of its surrounding to detect potential dangerous situations for the driver. Safety applications could avoid injuries, convenience and leisure applications could increase the comfort of the driver and passengers. In this paper, our main goal is efficient usage of available bandwidth and achieve a low-latency in delivering real-time information in various situations in VSN. One of the most prominent issues in vehicular networks regards the quick and scalable delivery of data among all participants that share the same application. We develop an architectural solution that allows vehicles dynamically estimate their transmission range and to exploit this information to effectively propagate a broadcast message with as few hops and transmission as possible.**

Keywords—Vehicle to Vehicle (V2V) communication; Vehicular Sensor Network (VSN); on-board-unit; Dedicated Short Range Communication (DSRC);

I. INTRODUCTION

Vehicular ad hoc networks (VANETs) are particularly challenging class of Mobile ad hoc wireless networks (MANETs) that are currently attracting the extensive attention of research in the field of wireless networking as well as automotive industries. VANETs have some characteristic differs from MANETs, such that vehicles in VANETs move follow the lane direction and will close to destination as time pass by. Vehicles also move in very high speed that often ranges 40-140km/h. VANETs are scalable, so vehicles as node in MANETs are infinite. Vehicles equipment, device mounted on vehicles, called on-board unit (OBU) that can wirelessly communicate with other vehicles using Dedicated Short Range Communication (DSRC) [1] and simple computer power. OBU in vehicles, its energy can view as infinite because vehicle always has dynamo that can generate energy from fuel.

The major objectives of vehicular ad hoc networks can be stated as follow [2]:

- Broadcast warning messages to neighbouring vehicles in case of car accidents, obstacle, bad weather condition and emergency braking on the road.
- Provide drivers with latest real-time traffic information.
- Help drivers to find accessible parking space.
- Receive online mechanic help when the car breaks down.
- Entertainment purpose e. g. multimedia, online gaming etc.

In VANETs scenario there are three most crucial challenges playing a vital role to achieve stable and effective communication mentioned below [3]:

1) How to efficiently utilize limited bandwidth?
2) How to maintain the dynamically fragmented topology? and
3) How to achieve low-latency in delivering real-time information in various situations?

A major challenge in the deployment of VANETs is the efficient usage of available bandwidth considering the large number of applications and the even larger number of network nodes. Especially multi-hop dissemination of information, which is required by some applications, creates a considerable scalability problem. In VANETs, alert message propagations are sensitive to per-packet delivery delays. So the quick propagation of multi-hop broadcast message generated by the applications requires the deployment of specific solution able to avoid redundant transmission and other messages propagation delays. We propose a solution in which we modify the layered architecture with the use of NS2 for range estimation. This technique allows vehicles to dynamically estimate their transmission range and to exploit this information to effectively propagate through broadcast message with as few hops and transmissions as possible. Also the farthest vehicle in the transmission range of a message sender/forwarder will be statistically get benefits in becoming the next forwarder.

The whole paper is organized as follows: section II gives a detailed overview of the literature survey that had been done. Section III gives details of our proposed architectural solution: Range Estimation Multi-hop Broadcasting in VANETs and section IV explains the fundamental details of proposed protocol with practical example. The experimental results are presented and discussed in section V and finally conclusion is given in section VI.

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II. RELATED WORK

Various 802.11 based solutions are proposed to reduce the delivery delay due to an excessive number of transmissions. For example, [4] proposes a back-off mechanism that reduces the frequency of message transmission or retransmissions when congestion is causing collisions and propagation delays. In [5], instead, as soon as a car receives a broadcast message from a following vehicle, it refrains from forwarding it, as the reception of this message is a clear confirmation that subsequent cars have already received it. Message forwarding can completely be stopped by a car as soon a following vehicle also starts to forward the message. It is felt that, both of these schemes have not considered a very important factor in determining the final propagation delay of a message: the number of hops a broadcasted message required before covering its whole area-of-interest.

DV-CAST [6], a distributed vehicular broadcast protocol for vehicular ad hoc networks, utilizes local topology information (i.e., a list of one-hop neighbours) as the main criterion to determine how to handle the rebroadcast of the message. This protocol divides the vehicles into three categories like well connected, sparsely connected, totally disconnected neighbourhood. This protocol causes high control overhead and delay in end to end data transfer.

In [7], authors propose a cross-layer scheme, called Dynamic Backbone Assisted-MAC (DBA-MAC) protocol as a general solution to support geocast communication on highway scenarios for different classes of vehicular applications.

In [8], the scheme builds Minimum Connected Dominating Set (MCDS) from graph theory to reduce the number of hops. In this, nodes represent the vehicles in the group, and an edge represents the connection between two nodes if the second node is in the transmission range of the first node. The implementation of this algorithm for V2V leads to number of practical problems as it would require complete and continuously updated knowledge of the network topology. Moreover, the high mobility of vehicular networks may render obsolete the MCDS even before its completion.

Due to clustering in VANET, some work proposed in [9] recommends the use of opportunistic diffusion of data in which message are stored in each intermediate node and forwarded to every encountered node till the destination is reached. Thus the delivery ratio is improved, but it is not suitable for non-delay tolerant applications.

In P2P solution[10], the source node stores the data in its storage device and do not send them in the network till another node asks for them which is not good for delay tolerant applications.

In [11], hops' minimization is achieved by individuating the farthest car within the source's backward transmission range, which has to forward the message. To this aim, jamming signals are emitted by each car with a duration that is directly proportional to the distance between the considered car and the message's source. The car with the longest jamming signal is clearly the farthest car from the source. Even if this guarantees a minimum number of hops to cover the whole area-of-interest, the time wasted to determine the next forwarder through jamming signals could make this scheme not suitable for a tight time delay scenario as the one we are considering.

A final scheme trying to statistically achieve a minimum number of hops when propagating a broadcasted message is discussed in [12, 13]. Both the schemes assign different contention windows (CWs) to each car receiving a message to minimize the number of hops. Each of the cars using V2V communication randomly selects a waiting time within its CW before forwarding the message (if nobody else already did) because their respective CWs are inversely proportional to the distance from the previous sender. However, these schemes are affected by the assumption that there is a unique, constant, and well-known transmission range for all cars in every moment. This is obviously not realistic.

Instead, we propose a position-aware broadcasting scheme that is able to reduce the number of forwarding hops based on the transmission range estimation. With our scheme, broadcast messages are forwarded after a delay that depends on the node distance from the source and, peculiar of our algorithm, on a continuously estimated transmission range.

III. PROPOSED SOLUTION

We propose an architecture that ultimately do multi-hop broadcast of messages generated by a generic application. The vehicles having the OBUs will process the packets at their levels with modified code at MAC, Network and Transport layer. Ultimately, our solution gives V2V communication among vehicles in a group of cars, and its main features are listed below.

- It acts as a general solution framework which enables quick propagation of messages generated from various applications of any type and any rate for all of V2V communication applications.
- An algorithm is developed for providing efficient priority scheme to choose the next-hop forwarder. A message is rebroadcasted based on the distance from the previous sender and on the expected transmission range. This reduces unwanted retransmissions which at the end reduces propagation delays.
- Transmission range is estimated dynamically which represents a fundamental feature for the vehicular ad-hoc networks: a highly dynamic network. Though there is a small overhead caused by data that have to be exchanged among vehicles to appropriately get the transmission range, data for the transmission range estimator are directly fed through regular application messages if possible.

However, if there isn't any intelligence applied to the multi-hop broadcasting scheme, any node in the network would simply relay every received message. The subsequent effect would lead to high congestion, collisions, delays, and even to transmission paralysis of the vehicular network. This phenomenon can be seen as a particular instance of what is generally known in the mobile ad hoc network's literature as the broadcast storm problem [14].

In our proposed solution we have assumed that vehicles are equipped with onboard systems for communication, self-localization, monitoring, location awareness and entertainment. Also we have considered a group of cars that drive at various speeds ranging from 40-120km/h on a multilane highway road. It is understood that V2V communication may have frequent variations in terms of transmission range and available bandwidth. This is a realistic assumption since we have the availability of the DSRC/IEEE 802.11p technology which promises to provide vehicles with communication capabilities.

Our proposed architecture should be effective, regardless of the application in use. We may consider two practical case studies like road safety (accident alert communication, road conditioning, congestion etc.) and networked interactive entertainment (online gaming and shopping)[15]. We have tried our best to obtain the results that can be compared with obtained in[16].

IV. Range estimation multi-hop broadcast protocol(REMBP)

We have developed mechanisms to quickly broadcast, even through multi-hops, send alert messages from a vehicle behaving abnormally to all following vehicles in a range of kilometers, or video triggering messages to activate a video stream from a camera in a certain geographical location back to a requesting vehicle (e.g., first responders travelling toward an emergency area).

All these schemes made use of hello messages to have each vehicle able to compute its own transmission range and utilize it to reduce the number of hops, the totally transmitted messages, and hence the delay to cover the whole area-of-interest till destination. We show now how to apply these solutions to the case of different safety related and entertainment application related information dissemination, only exploiting regular event packets with no hello message overhead.

If we consider one of the networked interactive entertainment applications such as online gaming, REMBP is designed to quickly deliver game events to players in a certain gaming car group. This protocol is run by all vehicles which are engaged in the online session and its main feature is each vehicle can estimate its current transmission range both forward and backward. Vehicles' current estimations are included in every event sent by those vehicles so as to have all other vehicles in range aware of them. Ultimately, vehicles receiving broadcast events can use this information to determine their position within the sender's transmission range and to assign themselves a priority in becoming the next forwarder of the received message.

The rationale of this scheme will be clear with the help of Fig. 1, which shows a group of cars running on highway.

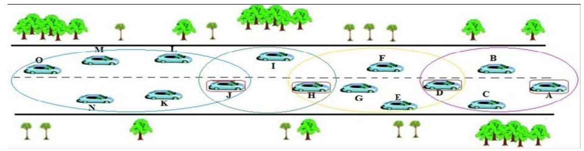

Fig. 1: Message Forwarder Selection: an example

For simplicity, we suppose that cars in the figure are located 200m apart and that the transmission range along the road is variable due to environmental conditions. Cars move from left to right and each circled area represents the backward transmission range of the rightmost vehicle in that area. Therefore, in Fig. 1 we have that car A has a transmission range of about 400m, thus being able to reach within a single transmission hop cars B, C and D; then, car D has a transmission range of about 600m thus being able to be heard directly by cars E, F, G and H; and so forth. In this situation, if we pretend that car A sends out a game message that has to reach all vehicles in the gaming car group, then the optimal solution would be represented by having (only) cars D, H, and J forwarding it. However, this optimal solution can be generated only if cars can be aware of their position within the sender's transmission range. Cars D, H and J have to realize that they probably are the farthest car in the transmission range having heard the last message to realize that they have to take upon themselves the task of being the next forwarders. This is the reason for having continuously updated transmission range estimation: by including this estimation in game messages.

Our scheme is composed of two phases. The first one, named Transmission Range Estimation Phase, is continuously active and is meant to provide each car with an up-to-date estimation of its backward transmission range. Instead, the second one is performed only when a message has to be broadcasted to all cars in the sender's area-of-interest and we name it broadcast phase.

Transmission Range Estimation Phase

In this phase, each car estimates its transmission range by the use of hello messages. For updating the transmission range of individual car, time is divided into turns. The information collected during a certain turn are kept also for the whole duration of the next one, and then discarded. Collected information for the current turn is represented by Current Front Maximum Transmission Range (CFMTR) and Current Back Maximum Transmission Range (CBMTR). CFMTR represents the estimation of the maximum forward distance from which another car along the road can be heard by the considered one and CBMTR represents estimation of the maximum backward distance at which the considered car can be heard. There is a mechanism to keep both the variables updated continuously via received hello messages until the current turn expires and, at that point, their values are stored in the Latest Front Maximum Transmission Range (LFMTR) and the Latest Back Maximum Transmission Range (LBMTR), respectively. We keep record of both a last-turn and a current-turn value because the former guarantees to have a value computed with large number of hello messages, while the latter considers fresher information.

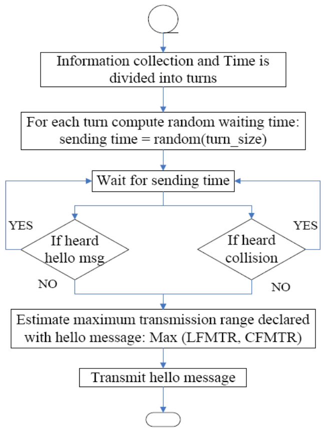

Fig. 2: Hello message sending procedure

The transmission range estimation phase is best explained with the help of Fig. 2 and Fig. 3. We explain our scheme's behavior during the procedures for sending hello messages (Fig. 2) and receiving hello messages (Fig. 3), respectively. In hello message sending Procedure, in every turn, each car determines a random waiting time. After waiting time, if neither other transmission is heard nor collision happened, it proceeds with transmitting a hello message which contains the estimated maximum frontward transmission range.

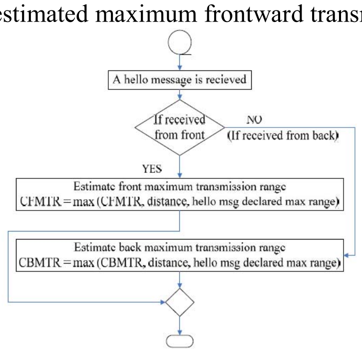

Fig. 3: Hello message receiving procedure

A hello message is received at car includes position of car, hello message sender car's position, hello message declared maximum range and the distance between message receiving car and hello message sender car. The generated messages causes very less overhead. In fact, no more than one hello message is sent every turn by cars in the range of each other, regardless the number of cars n.

The hello message receiving procedure is explained in Fig. 3. In this procedure, a car receiving a hello message determines its own position. After extracting the information of sender's position and the included estimation of the maximum transmission range, it determines the distance between itself and the sender. If the hello message is received from ahead the value of CFMTR is updated, otherwise CBMTR is updated.

Message Broadcast Phase

The transmission range estimation phase is used for making cars aware of their transmission range through the procedure of hello message exchange, while message broadcast phase is used to reduce transmission redundancy and achieve a quick delivery of message. Each of the cars uses this transmission range information to assign itself a priority in forwarding the broadcasted message based on its distance from the message sender. The logic for the case is higher the relative distance, the higher the priority. The broadcast phase is activated by the ongoing application in vehicles and generates a broadcast message that has to be propagated over the interested area of the sender. This broadcast message contains information related to the supported applications as well as data utilized by the broadcast algorithm, which includes, the fields: Sender_Position and Max().

Max() is a typical parameter of our algorithm and represents how far that transmission is expected to go backward before the signal becomes weak and undetectable. This value will be used by following cars to determine which one among them will become next forwarder. In particular, to minimize the number of hops, and hence the propagation delay, we want the farthest car to do this task of forwarding. Therefore, the higher the relative distance of the considered car from the sender with respect to the estimated transmission range, the higher the priority of the considered car becoming the next forwarder.

More in detail, when a car has to send or forward a broadcast message it computes the Max() value in the broadcast message as MAX (LBMTR, CBMTR). In our logic, cars' priorities to forward the broadcast message are determined by assignment of different waiting times to the time at which it is forwarded. The waiting time is computed based on a contention window (CW). If, during waiting, some of the cars already transmitted the message, preceding ones terminate their forwarding procedure. As we know, the larger the contention window, there are more chances of somebody else becoming a next forwarder.

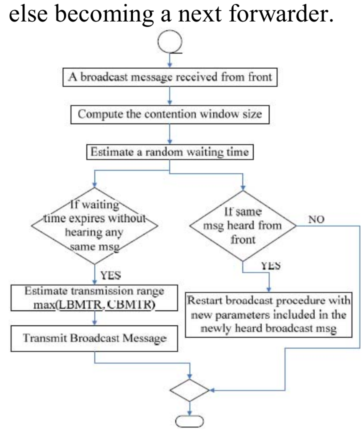

Fig. 4: Broadcast message forwarding procedure

The contention window of each car is varied between a minimum value (CWMin) and a maximum value (CWMax), depending on the distance from the sending/forwarding car (Distance) and on the estimated transmission range (Max()) declared in the broadcasted message. This is summarized by (1) and is used to determine which car will propagate the broadcast message on the next hop.

$$\left[\left(\frac{MaxRange-Distance}{MaxRange}\times(CWMax-CWMin)\right)+CWMin\right] \qquad \ldots\ldots\ldots\ldots(1)$$

Upon receiving a broadcast message from the front, a car utilizes (1) to determine its contention window (CW) and then computes a random waiting time based on it. If, during waiting time, the same message has been heard again coming from behind, the message has already propagated over the considered car that can hence stop trying to forward it: somebody else already have done it. On the contrary, if the same broadcast message is heard from front, meaning that a preceding car has already forwarded it. The procedure will restart with the new parameters included in the newly heard broadcast message. If the waiting time expires without having heard any other car forwarding the same message then the considered car will broadcast it with estimated transmission range. At the end, if the broadcast fail, a back-off mechanism is utilized to compute the next transmission time.

V. Results And Discussion

We modified MAC layer's parameters according to IEEE 802.11p and the configuration is summarized in Table 1. The time after which a hello message is generated is set equal to 100ms. This means that about ten hello messages with a payload of 50bytes are generated every second, within a transmission range area, (only) if no application transmission happens.

In these experiments, the length of the vehicular network varies from 1 to 6 Km and vehicles with communicating capabilities are placed in average every 20m, thus having from 50 to 300 vehicles that are involved in the transmission/ forwarding process. Among vehicles with communication capabilities, a number of them, varying from 2 to 50 and uniformly distributed over the vehicular network, are sending message among each other. This means that events are periodically generated in these nodes and broadcasted, even through multi-hop, to all other vehicles in the network. Actually, different sending rates are considered to test how the system behaves in presence of different kind of events, from fast message generation event to slower generation i.e., 100 ms, 300 ms, 500 ms, whereas the size of each game event was 200 Bytes, constantly. The actual transmission range varies from 300 m to 1000 m in order to test extreme values that have been declared by the IEEE 802.11p developing committee.

Table 1: Simulative configuration

Feature	Value
Wireless Model	Two-ray Ground reflection
Type of road	Highway with multiple lanes
Vehicle Speed	40-140km/h
Road Length	6km
Number of Vehicles	300
CWmin – CWmax	15 slots – 1023 slots
CW Slot Duration (Control Channel)	100µs
CW Slot Duration (Service Channel)	13µs
SFIS	32µs
Ideal time before hello message generation	100ms
Hello message size	50B
Application message size	200B
Transmission Range	300m – 1000m
Message Generation Interval	100ms, 300ms, 500ms

Focusing on REMBP's parameters, we have set CWMin and CWMax equal to 15 and 1023 slots, respectively, as inspired by the standard IEEE 802.11 protocol [17]. Four different slot sizes have been compared: 13µs, 100µs, 600µs and 1000µs. In particular, in the latter case, we expect to witness a reduced number of collisions among the events even if at the cost of an increased total delivery time.

Influence of the Time Slot Duration

We investigated the performance variation when employing different time slot sizes for the CW. We considered a scenario with 300m of factual transmission range and 50 simultaneous message senders. The outcomes shown in Fig. 5 represent the instantaneous variation of the delivery time of each single event to the farthest vehicle in the car group. Clearly, an increase of the total delivery time corresponds to longer time slot duration. When considering an accident alert communications, only small delivery delays are acceptable. Therefore, time slots larger than 100 µs would not be a feasible configuration.

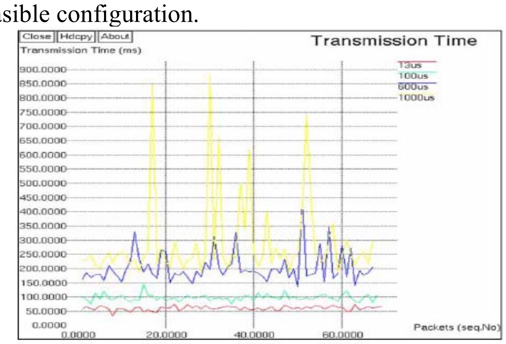

Fig. 5: Transmissiom time

However, too small time slot values could result in elevate collisions, interference, and lack of reliability in delivering each message. Fig. 5 shows the percentage of event messages that were successfully delivered to all vehicles.

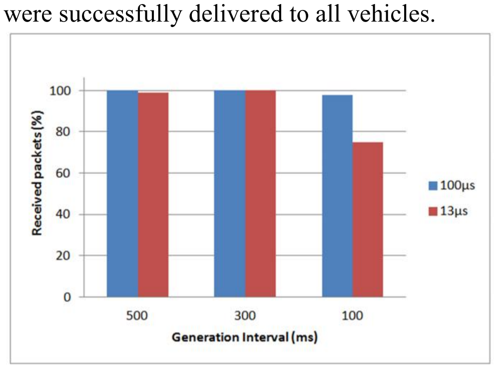

Fig. 6: Received packets

We compare different slot size for CW from 13µs to 1000µs. When employing time slots of 13µs, the increased delivery speed shown in Fig. 5 is paid with a noticeable reduction of reliability while message generation interval decreases to 100ms (see values for one message generated every 100 ms). In both Fig. 5 and Fig. 6, we have taken 6km long vehicular network, number of vehicles are 300 among which 50 vehicles are sending event message simultaneously with 300ms of message generation interval for each vehicle and 300m of transmitting range.

In summary, 100 µs is the only value among the tested ones that provided both fast and reliable message delivery. As expected, with higher message-generation rates, less time to compute the correct estimation is needed. This is a logic consequence of the fact that the estimation is based on data about vehicles' positions and "hearing" distances that are exchanged through application/hello messages. Therefore, the more messages there are, the more information is received, and the correct estimation can be built quicker.

VI. CONCLUSION

We designed a multi-hop broadcast protocol and provided an algorithm to practically implement it in vehicle to vehicle communication scenario. Simulation in VANET consists of two components: traffic simulation and network simulation. Traffic simulation focuses on vehicular mobility and it generates a trace file which provides realistic vehicles movement. This trace file is fed in to the network simulator which defines the realistic position of each vehicle during the simulation. We have generated mobility for urban scenario using SUMO (Simulation of Urban Mobility) [18], which gives collision free vehicle movement with high road density also, and NS2 [19] for network simulation. The main contribution of this work is the utilization of a transmission range estimator through which each vehicle becomes aware of how far each message will go and hence able to compute its own probability in becoming the next forwarder. Estimated actual values of dynamically computed cars' transmission ranges are used to minimize the number of hops to be propagated during the broadcast activity. We analyze the performance of REMBP under different parameter to check the reliability of message delivery. Results confirm that broadcasted messages reach the end of their area-of-interest with as few transmissions as possible, thus reducing the required delivery time. In future work the performance of this protocol will be analyzed for urban area such as Gandhinagar city in Gujarat. Fortunately, there is also a scheme Enhanced Message Dissemination based on Roadmaps (eMDR)[20], specially designed to improve the performance of the warning message dissemination process in real map urban scenario.

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