Enhanced Multi-Hop Vehicular Broadcast (MHVB) for Active Safety Applications

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***Abstract*— This paper, focuses on the "enhancement" of Multi-hop Vehicular broadcast (MHVB). The protocol is fundamentally a flooding algorithm with special characteristics in order to efficiently disseminate information such as the positions and the velocities of the vehicles for the sake of active safety applications.**

The main purpose of this paper is to show the performance improvements obtained by adding more special characteristics to the existing version of MHVB. The enhancement procedure is carried out in two steps: by changing the shape of the backfire region in the algorithm and by introducing a new Dynamic Scheduling algorithm which prioritizes the packet transmission based upon "processing" of the received packets from the other vehicles. The key point in the proposal made to enhance the broadcast protocol is the balance between the application requirement and the performance of the protocol.

I. Introduction

Mobile Ad-hoc NETwork (MANET) [1] is defined as a collection of mobile platforms and nodes where each node is free to move about arbitrarily. Each node logically consists of a router that may have multiple hosts and that also may have multiple wireless communications devices. The term MANET describes distributed, mobile, wireless, multi-hop networks that operate without the benefit of any existing infrastructure except for the nodes themselves.

The purpose of MHVB protocol [2] is to disseminate information in vehicular ad hoc network by efficiently flooding the packets among vehicles based on their position information. Based on the requirements of ITS active safety applications, a mechanism to detect traffic congestion and a method to suppress unnecessary packets for improving the bandwidth utilizations have been introduced. The introduction of congestion detection technique gave a significant impact on the improvement of the performance of flooding protocols in ITS context. However, the scalability of the protocol is not satisfactory because too many packets transmitted by many nodes lead to packet collisions and the consequent packet losses.

Many studies in ad hoc networking [3], [4], [5], [6], [7] propose mobility patterns in the two-dimensional plane. The nodes involved change their speed more or less randomly. However [8], vehicles in road traffic typically follow the road which allows us to reduce mobility to one dimension.

II. Related works

Message forwarding can help warning messages reach beyond the radio transmission range. In [9], over a short period immediately after an emergency event, the faster the warning is delivered to the endangered vehicles, the more likely accidents can be avoided. The vehicle can be identified as an abnormal one if there is a deceleration exceeding certain threshold, dramatic change of moving direction, major mechanical failure, etc.. A receiver of the warning messages can then determine the relevancy to the emergency based on the relative motion between the abnormal vehicle and itself. When an emergency event occurs, there are usually a group of vehicles affected by the abnormal situation. In terms of group management, [10] defines so called "proximity group" based on the location and functional aspects of the mobile hosts.

Flooding protocols for ad hoc networks are extensively summarized in [11]. It classifies the broadcast techniques for Mobile Ad Hoc Networks (MANET) largely into four kinds :

- Simple flooding, in which all the nodes receiving the broadcast message rebroadcast the packet exactly one time and these rebroadcasts are repeated until all the nodes receive the packet.
- Probability based methods, which are similar to simple flooding except that the nodes rebroadcast with a predetermined probability.
- Area based methods in order to cover as wide area as possible, the node which can cover larger additional area is chosen as a rebroadcast node. Namely, the farther nodes from the sender preferentially rebroadcast the packet.
- Neighbor knowledge methods: Ideally, Minimum Connected Dominating Set (MCDS) is the set of nodes able to rebroadcast the packet with the least number of packets. However, since the problem of MCDS is known to be NP-hard for general graphs, these methods aim to disseminate the information with as less packet as possible by calculating the localized sub-optimal solution based on the knowledge of neighbors.

The approach shown in this paper belongs to area based methods. The reason why this approach is chosen is that we assume that a location device, such as Global Positioning System (GPS) or Galileo devices, will be available in all vehicles in the near-future and that the protocol can then exploit their position information.

III. Enhanced MHVB

A. Backfire algorithm

The backfire algorithm helps to identify the right forwarding node based upon its relative position from the sender; that forwarder will refrain, i.e."backfire", other potential nodes which have lesser coverage gain by their eventual forwarding. In the earlier version of MHVB protocol [2] the shape of the backfired region is a circle where, among the potential nodes able to retransmit the information, only the farthest node from the original sender retransmits the packet, so that the coverage gain is bigger, assuming message transmission in the forwarding direction. In the enhanced version of MHVB a sectoral backfire (see Fig.1) is implemented with its angle as an extra parameter. The main advantage by implementing such a type of backfire is that by changing the angle of the sector we can modify the area covered for backfire, resulting in a "flexible" and "directional" backfiring region.

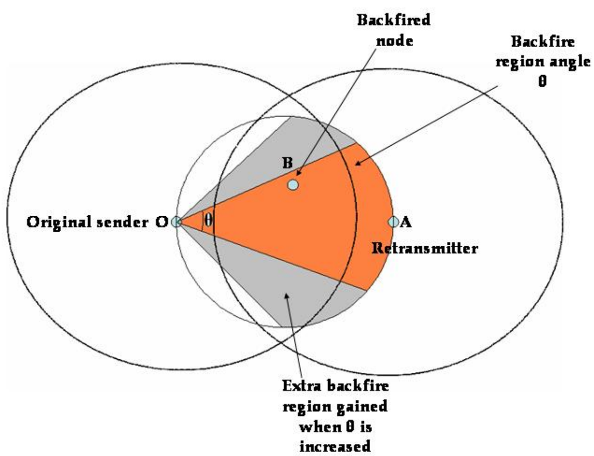

Fig. 1. Sectoral backfire

Putting **a** as the relative position vector from node A to O and **b** as the relative position vector from node B to O and θ as the angle of the backfire region, the following are the conditions for B to get backfired when it receives the retransmitted message from A is:

$$(\bmod a) > \quad (\bmod b) \tag{1}$$

$$\frac{\mathbf{a} \cdot \mathbf{b}}{(\bmod a) \cdot \quad (\bmod b)} \geq \cos\theta \tag{2}$$

$(\bmod a)$ and $(\bmod b)$ are the absolute relative positions of node A and B respectively from the original sender O.

B. Traffic Congestion Detection algorithm

This algorithm is based on a specific application requirement of vehicular active safety that the vehicles in the middle of traffic congestion should be generally detected by short-range sensors, and consequently the information by V2V communications is less necessary. So the vehicles which are in the middle of traffic congestion need not to transmit information as frequently as the ones which are at the edges of the traffic jam or out of it.

This condition helps MHVB work more efficiently. By counting the number of vehicles surrounding a concerned node, MHVB can detect whether the vehicle is situated in the middle of traffic congestion. If it is the case, it expands the interval of transmitting his own information, therefore saving bandwidth and reducing collisions.

C. Dynamic Scheduling

In the previous version of the protocol, the transmitter and the receiver modules of a node work in an asynchronous fashion i.e., each node transmits information periodically based upon the delay time computed due to congestion detected by analyzing the message cache and in the case where there is no congestion detection, the transmission takes place periodically every 0.1 sec with some jitter in the transmission (between 0.08 sec 0.1sec). Thus the timer for the next transmission is "pre-determined" ahead of one transmission interval.

Now, the idea is to modify the pre-determined time upon each reception of information of the node thus making it dynamic. Here the nodes which are at a distance farther than 200m are made to transmit the received information earlier than all the other nodes in the network i.e, the next transmission time is changed between (0.07sec 0.08sec). Thus the time which was set during the transmission by the process of congestion detection is changed during the reception. When the distance between the receiver node and the sender of information is more than 200m, the receiver resets the scheduled transmission time earlier than before and thus it can re-transit before the other nodes do. In this case, the waiting time of the packet to be re-transmitted is set to zero so that the node which received the packet will transmit at once in its next transmission time.

By the above process the advantage is two fold. The packet is forwarded more quickly because an emergency warning message has to transmitted more quickly and for a longer distance which is the ideal condition for high speed scenarios. The second advantage is that when the nodes in the range greater than 200m transmit information earlier, they indirectly backfire the nodes in the range lesser than 200m and thus saving the network resources at lesser ranges.

IV. Scenarios

Basically there were three scenarios used for validating the protocol and comparing with the previous version. They are,

1) Random Waypoint model
2) Single Lane Model
3) Typical Highway scenario with intersections

The random way point model is used to test the worst case working condition of the protocol, in order to show how far the performance improves with the enhanced techniques. The scenario is a two dimensional grid which consists of certain number of nodes within an area of 1000 sq.m. The simulation time runs for about 100secs and the number of nodes vary from 10 to 100. Fig.2 shows the scenario

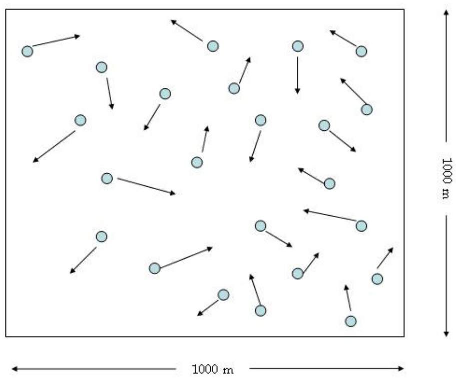

Fig. 2. Random Waypoint scenario

The Single lane model was selected to check the basic performance of the protocol itself. Nodes were placed as shown in Fig.3 at regular intervals without any movement in a straight line for a certain distance. The number of nodes are also changed in order to check the performance in terms of density variation.

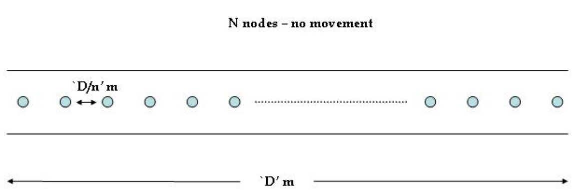

Fig. 3. Single lane scenario

In order to see what happens in a real time situation, a typical highway scenario was generated. This scenario contains four lanes intersecting each other in a two-by-two fashion. This was sub-divided further into two scenarios where the relative velocities at the adjacent lanes are higher in one scenario and lower in another scenario. The highway model with crossroads is shown in Fig.4.

V. RESULTS

A. Application requirement

Considering the applications for emergency warning systems, the target application requirement stated that the information

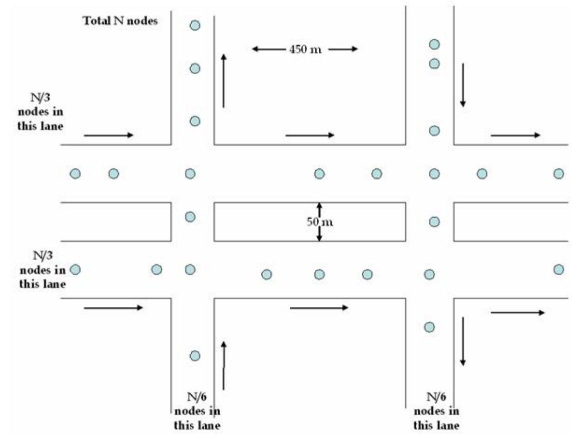

Fig. 4. Highway scenario with intersection

to be transmitted for a distance of 400m within a time span of 0.3secs. Thus we define a performance parameter "Success rate" which is the ratio of the number of packets received within 0.3secs by a node to the total number of packets received by the same node during the entire simulation time T. Ideally speaking, the ratio should be 1 for distances less than 400m and 0 for distances greater than 400m. Fig. 5 shows the ideal characteristics of the MHVB protocol

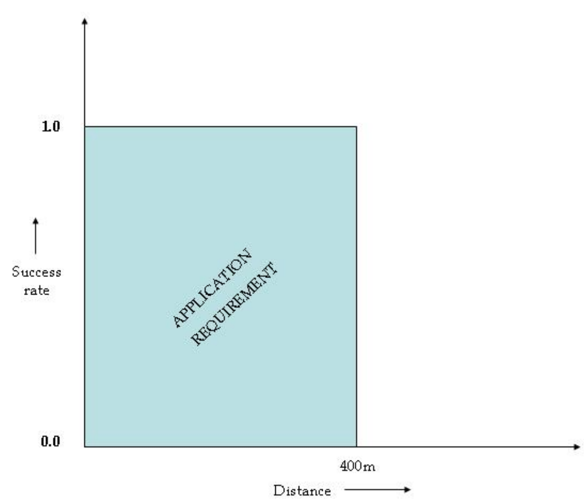

Fig. 5. Ideal Application requirement

B. Performance of Sectoral backfire

Fig. 6 shows how far the Sectoral backfire improves the performance when compared to the Circular Backfire and the amount of improvement in the success rate even in the worst-case scenario. It can be inferred that for an angle of 10 degrees, there is increase in performance of about 15-20%. There were

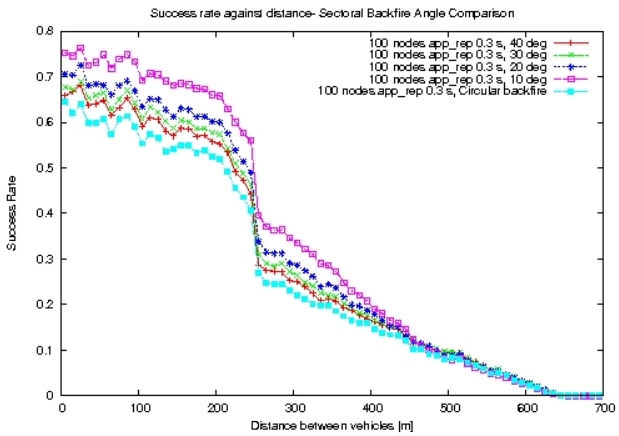

Fig. 6. Performance of Sectoral Backfire on Random Waypoint model

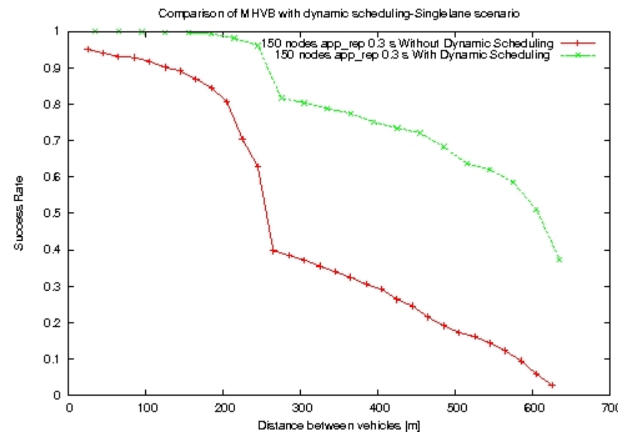

Fig. 8. Single Lane scenario- No node movement

100 nodes placed in a 1000m x 1000m square area and were set in random motion for a simulation of time of 100 seconds

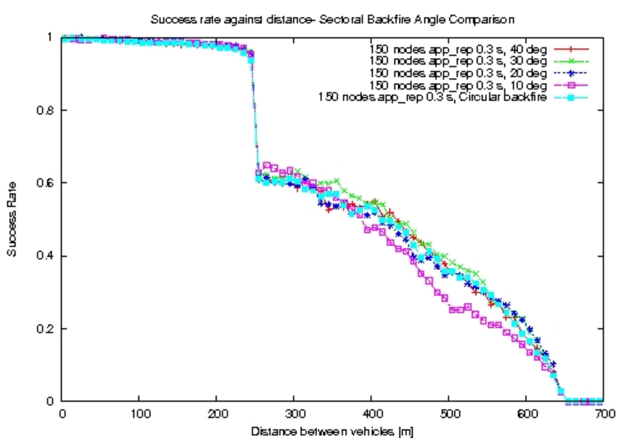

Fig. 7. A typical highway scenario with intersections

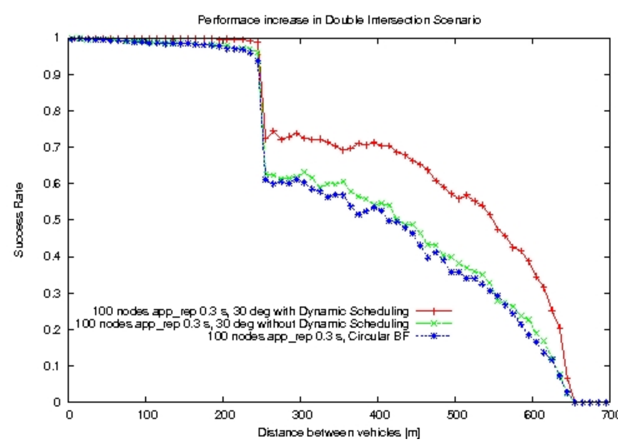

Fig. 9. Highway Scenario with intersections

Fig. 7 shows the simulation result of the highway scenario with lower relative speed between the nodes. With an angle of 30 degrees for the backfire, the protocol out performs the circular backfire by a small margin.

C. Performance of Dynamic Scheduling

Now that we have seen that the sectoral backfire does better than the circular backfire, the following simulation results will prove how much better is the dynamic scheduling algorithm when combined with the sectoral backfire.

The Fig.8 shows the amount of increase in performance obtained by implementing the dynamic scheduling algorithm for a single lane scenario. The nodes were arranged at equal distances and were non-mobile. It can be inferred from the figure that there has been an significant improvement in the success rate. This scenario which has been used to test the basic performance of the protocol shows a 40% increase in performance above the radio range when compared to the primitive version and a 5-10% increase within the radio range.

Now, considering a typical highway traffic scenario with intersections, there is a success rate of almost 100% within the radio range and an increase in the performance about 15-20% above the radio range when compared to the simulations without dynamic scheduling algorithm. This proves that the newly implemented techniques are suitable for traffic like scenarios.

D. Performance based upon relative speed between lanes

Fig. 10 compares the results obtained by implementing the Dynamic scheduling procedure with the sectoral backfire of 30 degrees and the previous protocol without scheduling. This result is obtained by considering the average relative speed of the vehicles between the lanes as the performance parameter. The overall performance increase is found out to be 10-20% outside the radio range and almost a success rate of 100% within the radio range. Also, we can notice that the success rate outside the radio range is higher by a small but significant margin for traffic with higher relative speed; a favorable result for the vehicles with higher relative speed between lanes.

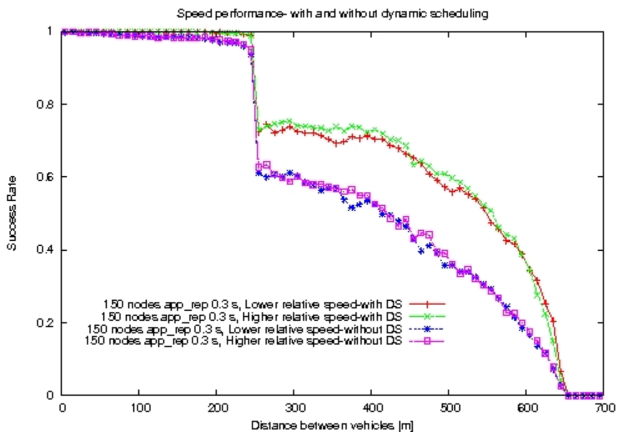

Fig. 10. Speed performance: Highway Scenario with intersections

E. Performance based upon density

Now a comparative analysis is done with respect to density of the nodes present on a given area for the following scenarios,

1) **Random waypoint model**

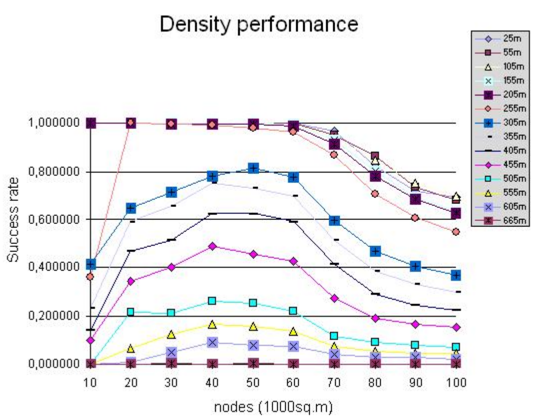

Fig. 11. Density performance: Random waypoint model

The random way point model is used to test the performance in the worst-case. Within the radio range there is 100% success rate in the information reaching a node conforming to the application requirement, for node densities up to 50 for an area of 1000sq.m . After the radio range, the success rate is low for lower node densities because of the sparseness present in the network, reaches a maximum value thereafter, for about 50-60 and then a decrease for further increase in the number of nodes.

2) **Single Lane model**
Focusing back to the Single lane model which checks the basic functionality of the protocol, there is almost 100% success rate within the radio range for nodes density up to 50nodes/1000m long lane and then gradually decreasing for higher node densities.

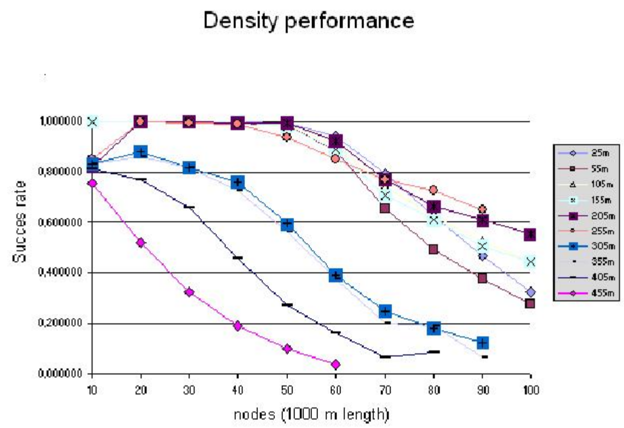

Fig. 12. Density performance: Single Lane model

F. Performance based on different application requirements

This section describes the performance based upon different application requirements. There are mainly 3 application requirements considered here for the purpose of simulation. They are

1) Message transmission within 0.3 second up to distance of 400m
2) Message transmission within 0.5 second up to distance of 400m
3) Message transmission within 1.0 second up to distance of 400m

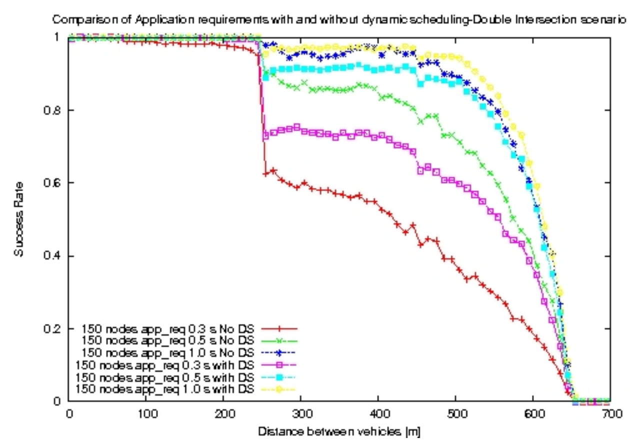

Fig. 13. Highway Scenario with intersections: With and without dynamic scheduling

Fig. 13 summarizes the simulation results of the double intersection scenario for different application requirements and thus compares the performance of the MHVB with dynamic scheduling and the one without dynamic scheduling. In this simulation, there are 150 nodes involved on a Highway for a simulation time of 100 seconds. There is a clear increase in performance at every stage of application requirement.

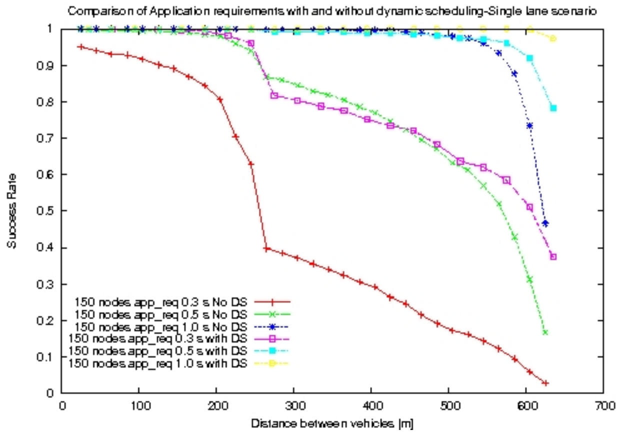

Fig. 14. Single lane scenario: With and without dynamic scheduling

Fig. 14 summarizes and compares the results of different application requirements for the cases of with and without dynamic scheduling algorithm. As described in the previous section, this scenario comprises 100 nodes placed in a long lane of 1000m length without any movement. From the figures shown it can be seen that as the time with the implementation of the dynamic scheduling algorithm, there is a clear performance increase by saving the network resources. When the requirement becomes weaker, the overall performance approaches the ideal characteristic of the application requirement as shown in Fig. 5 and lesser is the performance increase when using the dynamic scheduling.

VI. Conclusion

In this paper, an enhanced version of the Multi-hop vehicular broadcast protocol is proposed. A comparative study is made with the previously existing MHVB and the improvements obtained to efficiently disseminate information in vehicular ad hoc networks are shown. The newly implemented sectoral backfire provides an efficient way of flooding based on distance and also the relative positioning of the sender and the receiver.

Introducing dynamic scheduling provides a significant improvement in terms of performance and in terms of saving network resources. The earlier re-transmit time for the nodes which are at a distance greater than 200m from the sender, enables to transmit emergency information earlier than other nodes which are closer to the previous transmitter.

Taking into account the application requirement stated for active safety applications, this enhanced MHVB protocol provides 100% success rate within the radio range for typical highway scenario and 15-20% improvement outside the radio range upto 400m. Considering the single lane which describes the basic performance, there is 100% success rate in the information transfer within the radio range and a 50% improvement in performance outside the radio range.

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