Bachelor's Thesis for the Degree of B.Sc. in Computer Science and Engineering (CSE)

Communication Requirements for Safety Applications in Low-Visibility for VANETs

Md. Mohaimenul Hossain
Zaheen Farraz Ahmad

Supervisor:
Dr. Muhammad Mahbub Alam

Department of Computer Science and Engineering
Islamic University of Technology

BACHELOR OF SCIENCE IN
COMPUTER SCIENCE AND ENGINEERING

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By
Md. Mohaimenul Hossain
Zaheen Farraz Ahmad

Supervised By
Dr. Muhammad Mahbub Alam

Department of Computer Science and Engineering (CSE)
Islamic University of Technology (IUT)
Organization of the Islamic Cooperation (OIC)
Dhaka, Bangladesh
October, 2012

Vehicular ad-hoc networks (VANETs) have been recently designed and envisioned be used to improve transport systems. Vehicular network applications exist in various areas to facilitate better driving experiences. Examples of VANET applications include safety applications, advertisement dissemination, multimedia broadcasting and Internet facilities inside the vehicles. Many safety applications have been designed to be incorporated into use with VANETs. These safety applications increase the safety of vehicular transportation by attempting reducing vehicular accidents and collisions. Examples of safety applications are intersection collision warning (ICW) which works to prevent vehicular accidents at intersections and emergency electronic brake lights (EEBL) which tries to reduce rear-end collisions caused by sudden emergency brakes. However, most applications do not address the situation of vehicular safety in low-visibility conditions such as fog. Our work provides an approach to model communication requirements necessary to reduce vehicular accidents on highways due to low-visibility. Our work also provides mechanisms and algorithms used to improve the efficiency of networks under these conditions.

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Chapter 1

Introduction

1.1 Overview

Vehicular ad-hoc networks (VANETs) have been recently designed and envisioned be used to improve transport systems. Vehicular network applications exist in various areas to facilitate better driving experiences. Safety applications are in use to increase driver safety by performing functions such as intersection collision warning (ICW) [1] and emergency brake warning [2]. Other applications for VANETs include dissemination of advertisements, multimedia applications and Internet availability.

1.2 Problem Statement

The importance of VANETs for safety applications is probably the most valuable use of VANETs and thus a majority of applications involve safety. However, most of the work done so far involve various scenarios in urban environments. Our work deals with safety on highways. More specifically, the prevention of accidents of cars on highways in low-visibility conditions i.e., foggy weather, where accidents are mainly caused due to a lack of knowledge of the presence of other vehicles. The problem is that there is currently no proposed system to specifically define the communication requirements necessary to prevent vehicular accidents on highways in low-visibility conditions.

1.3 Research challenges

We have faced several challenges. The first challenge is the detecting cars in low visibility. In low visibility caused by fog or heavy rain, it is hard to see four or five feet in front. A car driving in a moderate speed, it is hard to identify the car coming from front within a safety distance. Second challenge is to find an optimum speed and optimum transmission range of the vehicle as it has been seen that increment in the transmission range of the nodes that can increase the safety distance. However at the same time high transmission range also cause higher level of packet collision which cause low reception rate. The third challenge is to build the test bed in ns-3 and creating realistic highway scenario as there are many constraints present in real highways which can degrade the performance. Fourth challenge is to detect that, a car is from its own cluster or it is coming from another cluster. Adding of a node to a cluster and removing of a node of a cluster and change the transmission range accordingly is another challenge. Lastly another problem that we have been faced is that the low-visibility problem is currently in out of the spot light because it is a geographical based problem. Not all the area of the world is facing this problem. The problem is that, there is currently no proposed system to specifically define the communication requirements necessary to prevent vehicular accidents on highways in low-visibility conditions.

1.4 Motivation

The highways can be made total accident proof using VANET. VANET can play a vital role for avoiding terrible accidents. The main motivation for our work comes from the conditions of the highways both in developed and developing countries. Every year number of people is dying due to terrible accident in highways. And most of the lives taking accidents are caused by low-visibility problem. For improving safety conditions in highways many work has been done, however no one consider the scenario of low-visibility. These motivates us to do something new which can provide a better result and people can take a step ahead towards more safety driving. For our algorithm a paper written by Danda B. Rawat and Gongjun Yan ”Enhancing VANET Performance by Joint Adaptation of Transmission Power and Contention Window Size” has been a great help. We have used this papers partial concept to enhance the performance of the VANET so that it will provide a better performance in low-visibility.

1.5 Scopes

We are working with transmission range of the cluster head and the tail. We are also considering different schemes like intersection collision warning (ICW) [1] and emergency brake warning [2]. We have also implemented concept of flooding of messages. The field of safety driving using VANET is still relatively less discovered. Moreover the scenario of low visibility is yet to research. There is a huge scope of working on this field and bring the best result by combining two or more available protocols and also some new concepts. Different scenario like how to communicate between a GPS enabled car and a GPS non enabled car and many other scenarios can be discovered.

1.6 Our Contributions

Current work mainly provide use of safety applications in urban environments. Most unaddress the importance of applications for highway environments. They also assume that vehicles are being driven in normal-visibility conditions. So our work incorporates the strategies that are currently in use and tailors them for use in safety applications for vehicles on highways in low-light conditions and we also design a mechanism by which these vehicles can efficiently communicate with each other while allowing us to provide proper safety coverage. We propose an algorithm that increases reliability of the application by increasing the transmission range of a node with its velocity, a similar application which is shown in [5] which changes transmission ranges with the number of neighboring nodes.

1.7 Thesis Outline

Our thesis paper is divided into several chapters, each of which explains a different aspect of our research and work. Chapter 2 is a brief summary of all the papers that we have read for our research and motivation. Chapter 3 is divided into two separate sections. The first section describes the system environment and elaborates on the different aspects of networking involved in our mechanism. The second section describes in detail our proposed algorithm. Chapter 4 describes our method of simulation and then elaborates on our results and findings. Lastly, Chapter 5 summarizes our thesis paper and explains further work that can be done.

Chapter 2

Related Work

Haas and Hu [1] provide a system to prevent vehicular accidents at intersections in urban areas. They designed the requirements involved to detect whether vehicles turning at an intersection were in danger of colliding and modelled a system that would warn drivers of that danger.

Segata and Cigno [2] have worked on the use of VANETs to warn vehicles of emergency braking. They investigated the behavior of vehicles and the effect that has on how the vehicle brakes. They devised an algorithm to increase the efficiency of warning packets being broadcast to other nodes whenever a vehicle performs an emergency brake.

Guo and Wu [3] provide a system which would vary the transmission power of a node in relation the number of neighboring nodes. They provide a mechanism that finds the optimal transmission power that would result in a large coverage and a reduction in delay caused by simultaneous sending.

Lu and Poellabauer [4] investigate the effects of varying transmission range to delivery region ratios in an application specific conext. They show that increasing transmission improves the reception probability for nodes within the delivery region. Rawat and Yan [5] on the other hand provide an approach to vary the transmission range with the size of the contention window.

Bononi and Felice [6] design a cross-layered clustering scheme to improve communications between nodes. As a result, they design a method to create dynamic backbone clusters between nodes in close proximity. They group together nodes close together into a cluster and the information about the nodes in the cluster are shared between one another.

These are motivations in our work to design a system to work in low-visibility conditions. The work mentioned above do not provide mechanisms for use in highways or during low-visibility scenarios. But their techniques provide the inspiration with which we design our system.

Yair and Segal [7] have presented the "Distributed Construct Underlying Topology" (D-CUT) algorithm, which is a self-organized algorithm. The aim of this algorithm is to provide efficient and reliable hierarchical topology by minimizing the interference between network participants. This D-CUT algorithm produces a geographically optimized clustering of the network, by grouping dense and consecutive nodes into clusters which are separated by maximally possible gaps. This type of clustering allows strong connections between cluster members and reduces the inter cluster interference. In addition, it also gives a straight-forward for organizing and coordinating the vehicular network to achieve congestion control and efficient medium access performance.

Li and Lou [8] have worked with emergency message broadcast scheme that uses a small number of relays to achieve fast multi-hop EM propagation. At the same time they have tried to maintain a high level of transmission reliability, i.e., a minimum packet reception probability (PRP). They have introduced two types of relays to provide fast EM propagation and to enhance PRP simultaneously, so that low-latency, the desired reliability level and small overhead can be achieved at the same time.

M. Nekovee [9] derived bounds for the maximum acceptable message delivery latency and the minimum required retransmission frequency of communication protocols for rear-end collision avoidance applications. Though they have considered only rear-end collision however simulation showed that same thing can be also applied for head to head collision.

Torrent-Moreno, Mittag and Santi [10] have described a method to enhance broadcast reliability, where a protocol called D-FPAV was developed. D-FPAV limits the transmission ranges in the network fairly and reduces the power levels of interference. Broadcast reliability is improved in every vehicle's proximity.

Lu and Poellabauer [11] provide an analysis of the invisible neighbor problem and the impact the selected transmission range and packet generation rate of a vehicle. Moreover, their work also provides application-specific safety requirements. The main goal of their work is to minimize the number of invisible neighbors within a certain region of interest (ROI).

Y.Zang, L.Stibor, H.-J.Reumerman, and H.Chen, [12] mainly described a proper highway scenario and how to avoid local danger by using inter-vehicle communications in highway scenarios. Hua Qin, Wensheng Zhang [13] has described the communication between a node and an infrastructure. They have proposed schedule scheme for communication.

R.K. Schmidt, T. Kollmer, T. Leinmuller, B. Boddeker and G. Schafer [14] have done their research on transmission range. Specifically they have described how different kinds of interference have adverse effect on transmission range. Kanitsorn Suriyapaiboonwattana [15] and Tonguz, Wisitpongpha, Bai, Mudalige and Sadekar [16].

Chen and Cai [17] provide an Ad Hoc Peer-to-peer Network Architecture for Vehicle Safety Communications. Suthaputchakun and Ganz [18] provide a concept of priority while communicating between two cars or group of cars in a cluster. They have provide the network structure using IEEE 802.11e protocol.

M. M. Artimy [19] had worked on dynamic transmission range. He had given a unique concept of change in transmission range based on estimation of vehicle density. Balon and Guo [20] in all three papers they have described different way of broadcasting message or safety alert in a effective way for vehicular ad-hoc network. In [20] they also provide some method for increasing efficiency of the broadcasting.

X. Yang, J. Liu, F. Zhao, and N. Vaidya [21] have worked on vehicle-to-vehicle communication protocol for avoid accidents. They have worked on some different angle. They introduced a new term called cooperative collision warning which in fact very helpful in busy roads. Bai and Krishnan [22] has provided the reliability analysis of DSRC wireless communication for vehicle safety applications. For different scenario they have done their analysis.

Bai, Elbatt, Hollan, Krishnan, Sadekar, [23] they have done an extensive research on communication-based automotive applications from a wireless networking perspective. They have characterized and classified different operations. Among them research on safety applications are very effective for our work.

Chapter 3

Proposed Method

3.1 System Model

3.1.1 Current Situation

In certain countries i.e., Bangladesh, and India, highways are not constructed for vehicular safety. Highways in these countries usually have only two lanes which remain unseparated by a divider or safety rail. Furthermore, most of these highways do not have street lights to aid in vision. As a result, in the winter season, due to foggy weather, visibility might be reduced to as little as 5 meters. Also in countries such as China and U.A.E., the fog has a great impact on the number of highway accidents. Vehicles are vulnerable to head-on collisions and rear-end crashes since the drivers fail to recognize the presence of others due to low-visibility. Fog lights on the vehicles only improve the situation slightly. A vehicle with fog lights will have slightly better visibility and will travel at a higher speed. The variations in speed between different nodes may result in a rear-end collision.

3.1.2 Application Mechanism

Our work describes the use of a common mechanism used in most safety applications to detect vehicular collisions. The devices in the nodes are 802.11 devices and utilize global positioning system (GPS). In our scenario, the nodes send data packets that have the

$$< id, v, (x, y, z), dir, type, n >$$

where *id* is the node ID, v is the node's current velocity, (x, y, z) provides the GPS coordinates of the nodes, and *dir* is the direction vector of the node. *type* is a two-bit field that represents the type of node within a cluster of nodes from which the packet is sent and n is the size of the cluster.

The packets are continually being updated and broadcast by nodes. When the packets from one node, A, are received by another node, B, node B uses the information in the packet to store node A's location, distance, velocity and calculate the trajectory of node A in relation to itself.

In this manner, one node will be able to use the information and detect if there is a chance of collision between itself and another node. If a node detects another node that is traveling towards it, then using the velocity and the distance between itself and the other, it will be able to calculate the possibility of a collision. Similarly, when two nodes are travelling in the same direction, the information about the velocity and distance will allow the nodes to detect if a rear-end collision can occur.

For example, if we have one node travelling down a stretch of highway and at some time it receives a packet from some other node that the driver has not seen yet. If the information in the packet describes a vehicle that is coming from the opposite direction, the node will broadcast an acknowledgement. This acknowledgement, warns the oncoming vehicle of the presence of the node. If all nodes have GPS devices, then not only can we send packets describing a vehicles direction but we can also send the exact location and distance. In this way, the nodes will be able to identify and potential collisions or crashes. Now, there are chances that these packets will not be received quickly enough to take a safe course of action. But it still may allow the node to perform an emergency brake to prevent an accident. In this case, our application will send out an EEBL packet to warn others of the emergency brake and prevent any crashes as a result of it.

3.1.3 Networking Aspects

Aside from the working mechanism of our application, we considered various challenges in the design of our system. Our work considers the networking aspects of our application.

3.1.3.1 Clustering

Section 3.1.2 described the functioning mechanism of the application when there is only one node. However, in reality, vehicles on highways usually travel in small groups. We use this knowledge to introduce another aspect into our application. We can organize our nodes into clusters. Now communication needs are based on the intercommunication of different clusters. The special case mentioned above can be described as cluster that contains only one node.

In clusters, each node has knowledge of the other nodes within the same cluster. Nodes in a cluster broadcast packages to specifically assigned clusterhead. The clusterhead collects the packets from the other nodes and disseminates the packets throughout the cluster. In our application, we have clusters that consist of member nodes, a clusterhead, and a clustertail. Each node in a cluster also contains information about the cluster. It stores a list of all the nodes in the cluster, the clusterhead ID and clustertail ID, the size of the cluster (number of nodes in the cluster).

Let us consider the formation of clusters. If a node does not receive any packets for a certain threshold period, that node becomes the clusterhead and clustertail of a cluster with only one node. If the single node then comes into close proximity with another node the two nodes will form a cluster. This new cluster can be formed in two ways. In one way, another node may come up to the single node from behind. If the clusterhead receives several packets where the velocity of the new node is near constant and it keeps close proximity to the clusterhead, it becomes a member of that cluster and is sent an acknowledgement packet. If however, from the packets received the clusterhead sees that the new node has a higher velocity and the distance between the two nodes continue to change, then the clusterhead is being overtaken and the new node is not sent a cluster acknowledgement packet. The cluster acknowledgement packet contains the list of all the nodes in a cluster. Upon receiving a cluster acknowledgement packet the member nodes will update their lists. In the above mentioned scenario, the new node not only becomes a member but it will become the clustertail if it remains behind the first node or it will become the clusterhead if it remains in front of the first node after overtaking it. The calculation mechanism is similar to the one designed in [6]. Similarly, when regarding existing clusters with more than one node, a new node will join the cluster if it remains near the cluster, that is it stays in the region from immediate rear of the clustertail or immediate front of the clusterhead.

Members of clusters broadcast their packets to maintain the cluster. These cluster-maintenance packets contain the node list of the cluster and the size of the cluster. The cluster-maintenance packets have the information necessary to refresh the cluster information stored by each node. Depending upon the location of the nodes the clusterhead or clustertail may change. Any node that overtakes a clusterhead will become the new clusterhead and each node will update their list with this new information with the dissemination of the next cluster-maintenance packet. Likewise, when a node falls behind the clustertail it will become the new clustertail.

A node will leave a cluster if it overtakes the clusterhead and continually increase its distance from the cluserhead or if it falls behind the clustertail and continues to increase the distance between itself and the cluster. A clusterhead or a clustertail may leave the group in a similar manner. In that case, the node behind the clusterhead will become the new clusterhead and the node in front of the clustertail will become the new clustertail. There is also the case that a vehicle within a cluster will perform an emergency brake. When this occurs, the vehicles behind this will be warned about the emergency brake by the EEBL system and they will also stop. At this point, the cluster becomes divided into two new clusters. One cluster which continues in the direction it was travelling and one cluster which has slowed down or completely stopped. These clusters assign their new clusterhead and clustertail and the nodes will update the list upon reception of cluster-maintenance packets.

3.1.3.2 Broadcasting

The broadcasting mechanism of our application can be divided into two different phases. We can classify broadcasting into 1) intra-cluster broadcasting and 2) inter-cluster broadcasting.

Within a cluster we use intra-cluster broadcasting. This relies upon the use of multi-hop broadcasting technique. This mechanism is used to update information about the cluster. Nodes in a cluster periodically broadcast cluster-maintenance packets and these packets are broadcast over multiple nodes. Our application can use a varied range of broadcasting algorithms but the most effective would be to utilize a further-distance multihop broadcasting. In this mechanism, the member node which is furthest from the source of a cluster-maintenance packet will re-broadcast the packet.

A critical situation that must be considered in intra-cluster broadcasting is the broadcast of EEBL packets. Emergency braking is most important within a cluster because collisions from emergency braking is more likely to occur between nodes within a cluster. Whenever a node performs an emergency brake it sends out a warning packet. The broadcasting mechanism used is EEBLA [2]. The packet is broadcast by the braking vehicle to other nodes. This packet will only be rebroadcast by a node if it does not receive that packet a second time from another node.

Inter-cluster communication is used when warning one clusterhead detects the presence of an oncoming node or cluster. The clusterheads and clustertails periodically send out single-hop broadcast packets. These packets have the structure described in Section 3.1.2.

When a cluster member (head, tail or normal member) receives a packet from another clusterhead, it waits a short interframe space (SIFS) period and then sends an acknowledgement

Bits	Type
`00`	Member
`01`	Clusterhead
`10`	Clustertail
`11`	Single Node Cluster

Table 3.1: Type Field

to the source. In normal highway conditions there is a chance that one cluster will encounter at most two other clusters. This condition occurs at intersections or exits on the highway. In this scenario, with three clusters, when one clusterhead sends out a broadcast it is received by both the other clusters' clusterheads. In this scenario we are assuming that the clusterheads have received a packet. Both of these clusterheads will want to send an acknowledgement in response to the packet to warn the source clusterhead. So to reduce the probability of collisions, the clusterheads first wait SIFS period and then randomly select a 0 or a 1. The node that selects a 1 waits a backoff period before sending an acknowledgement. The backoff period is equal to the SIFS period plus twice the maximum propagation distance.

The acknowledgement packet that is sent when a node is detected has the structure described in Section 3.1.2. The *type* field in the packet is actually a two-bit field that contains information about the cluster. It signifies whether the packet is sent by a clusterhead, a clustertail and a normal member.

Table 3.1 shows which type of node is signified by each two-bit combination. When a node receives an acknowledgement using the information from these two bits the node can deduce its relative position to the other cluster. For example, if receives a packet with `01` in the type field from a node moving in the opposite direction, it will know that an oncoming cluster of vehicles is nearby. If it receives a `10` from a node moving in the other direction, it will know that it has nearly passed that cluster. As another example, if a node receives `10` and the direction of the source is the same as itself, it will know that it is approaching a cluster of vehicles from behind.

Using the information from these packets, if a packet is sent quickly enough, oncoming nodes will become aware of all the nearby vehicles and may take the necessary actions. However, there is a chance that an acknowledgement may not arrive quick enough and instead be received very late. Since we assume that the devices in the nodes are GPS enabled, we can calculate distance, velocity, location, trajectory. So if a packet is received very late, then it may result in a collision warning informing the driver of the vehicle that it is necessary to perform an emergency brake.

3.1.3.3 Global Positioning System

In our proposal we consider that all the vehicles are GPS enabled. Through GPS one vehicle can locate the positions of other vehicles from which the data packets are broadcast. Vehicles can have a fairly good idea about the positions of other oncoming vehicles by calculating the trajectories.

On the other hand if there is no GPS system enabled in the vehicle the positions and trajectories cannot be calculated. However as our system depends mainly on adapting transmission range, it will not provide the exact location of the oncoming vehicle but it definitely will notify the driver about the oncoming car before collision happens. They will also not be able to provide the opportunity to warn of imminent collisions. All the knowledge that nodes without GPS receive is the presence of other nodes and the ability to broadcast EEBL packets.

3.1.3.4 Transmission Range

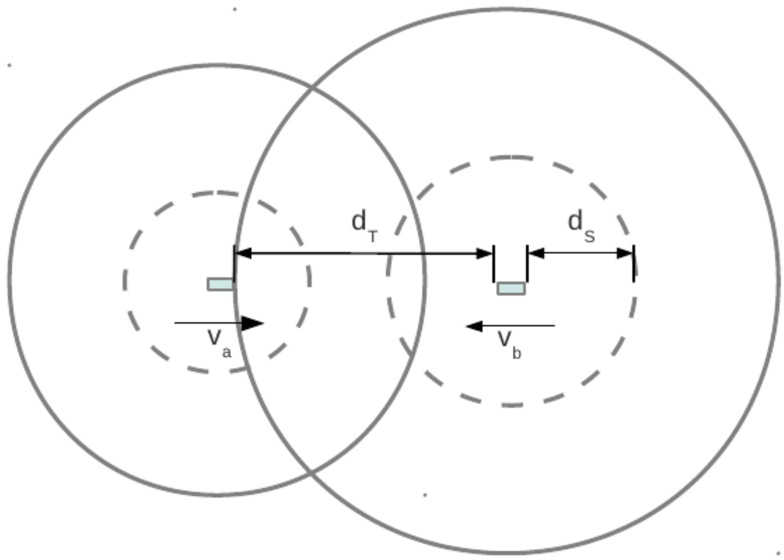

Figure 3.1: Model to Find the Safety Time Limit to Prevent Collision.

The model illustrated in Figure 3.1 explains the necessity of changing the transmission ranges in our scenario. Our application is very time-critical because vehicles have a rather low time-for-error. A slight delay in the reception of any message may cause the information of the existence of an oncoming node to come too late to be of any use. In current situations, which do not deal with low-visibility a driver will still be able to see if another vehicle is coming towards it. But we are working in the situation where the driver will not have that advantage. So it is necessary that all packets arrive as soon as possible. At a given velocity, v, a vehicle will require a minimum distance of d_s to be able to brake or move out of the way of any car coming towards it. This is the safety distance. In Figure 3.1, let the node on the left be node A and the node on the right be node B. Node A will detect node B and broadcast a packet back to node B to warn that he is coming in the opposite direction. It can be seen that node A can detect node B at the earliest from a distance d_T, the transmission range of node B. But that may not always occur due to delays from channel degradation or by interference from simultaneous sending of packets from other nodes. So node B must be detected by node A and receive a packet from node A before node A reaches the safety distance of node B. In Figure 3.1, the ranges around node B are shown larger to clearly illustrate the safety and transmission ranges. In reality, the two nodes would have similar safety and transmission distances. It is apparent from this description that we have a certain time in which to send the data, that is, node A must send a packet to node B before reaching node B's safety distance. This time window, which we call, safety time, can be calculated from the following equations. In these equations, v is the velocity of a node, d is distance, and t is time. d_{T_b} represents the transmission range of node B and d_{S_b} represents the safety distance of node B.

$$v = \frac{d}{t}$$
$$\Rightarrow t = \frac{d}{v}$$
$$\Rightarrow t_b = \frac{d_{T_b} - d_{S_b}}{v_a - v_b} - t_R$$
$$\therefore t_b \propto \frac{1}{v_a - v_b}$$
$$\therefore t_b \propto d_{T_b},$$

where t_R is the driver reaction time.

In effect we can see that, that the safety time of node B is proportional to the transmission range of node B. Therefore, we can provide a mechanism which increases a node's safety time by increasing it's transmission range. However, it is known that as we increase the transmission range of a node, the delay caused by interference from other nodes increases. This is because in the presence of other nodes, increasing the transmission range of the nodes increases the number of nodes with which they can communicate. Hence there is greater chance of collision from simulatneous sending. So our mechanism must find transmission ranges which allow for a better safety time while also keeping the delay low.

3.2 Proposed Algorithm

Our algorithm proposes to reduce the delays in transmission of packets caused by the interference of simultaneous sending and interference due to hidden terminals. In order to reduce transmission delays caused by these factors, one approach is to reduce the transmission range of a node by decreasing its transmission power. However, due to the time dependent nature of safety applications in low-light conditions, it is imperative that we increase the time duration in which packets are sent. This requires that we have a transmission power and the analytical proof is shown in our model.

Our algorithm, hence, tries to find a balance between decreasing the delays of broadcasted packets and increase the safety window of time in which they can be sent and received.

The algorithm can be divided into three different phases: 1) a set of steps that are required for a vehicles leading a group of vehicles traveling in close proximity to one another, and 2) a set of steps for all other vehicles within that group, and lastly 3) a set of steps for the trailing vehicle.

At first let us consider vehicles that are traveling alone. These vehicles do not suffer from transmission delays from collisions caused by simultaneous sending. Therefore, these vehicles can broadcast packets at the maximum possible transmission range to take advantage of a higher safety window.

In groups of nodes, or clusters, the lead vehicle will collect packets from the other nodes and broadcast these all together in an aggregate packet, which also includes the size of the cluster. This packet can also be called the acknowledgement packet.

Next let us consider the algorithms functioning for the clusterhead of a cluster. The clusterhead is the most important node in our collision warning system for obvious reasons. Thus, it is necessary that receive the fullest possible benefit from a higher safety window. The clusterhead in a group will use the highest signalling power. But since they are still near other nodes, it is necessary to try to decrease the number of packet collisions and so the transmission range of the node will vary with its velocity. As the nodes velocity increases, its signaling power also increases so as to compensate for the shrink in safety window due to a higher velocity. Likewise, a gradual decrease in velocity will cause the transmission range to shrink. The node will continue to broadcast packets periodically. The broadcast packets contain information about the node's attributes including the node ID, its velocity, its (x, y) coordinates, its direction, and the source type. Based on the broadcasting algorithm used, the lead car may send individual packets or aggregate packets in the acknowledgement which comprise packets from the nodes behind the clusterhead. When our vehicle detects a packet from an vehicle coming from the opposite direction then the node will send out a broadcast packet to warn the oncoming vehicle and any following vehicles. In order to reduce adverse effects of any false positives, our broadcast warning will be immediately sent only after receiving two packets from an oncoming car. A difference in behavior occurs during emergency braking. If the lead vehicle undergoes a deceleration that exceeds a certain threshold value, we regard it as emergency braking. In this special case of deceleration, the transmission power of the node will not be decreased. Instead it will remain constant and the node will flood an EEBL/R/A packet [2]. This means that the node will broadcast a packet to all other nodes giving a warning about the emergency brake so

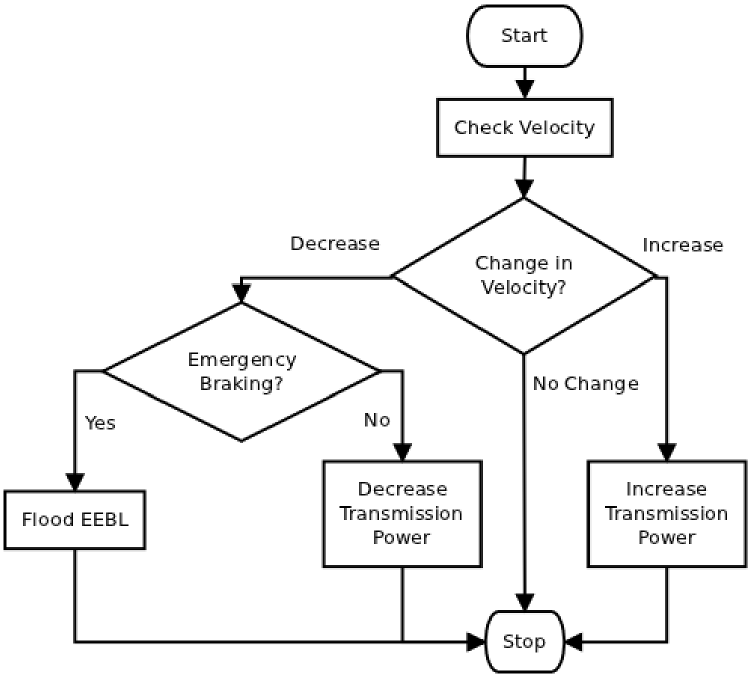

Figure 3.2: Flowchart of Transmission Adaptation Algorithm

as to prevent any rear-end collisions.

The next case we have to consider is the algorithm for all other vehicles in the group of vehicles. If the node is not the clusterhead or clustertail, then it will have a much reduced transmission range. This is to reduce the delay that the lead vehicle may experience as it is vital that the lead vehicle experiences lowest possible delay. But it is important that the transmission range of this node alters with its velocity so that it will detect collisions with the vehicle in front of it. Therefore, we can say that the transmission range must cover at least the node to the front, and to the sides. The transmission range will vary with the velocity but at a lesser degree than the lead car so as to compensate for any change in the safety window to prevent rear-end collisions. The transmission range will also increase if the distance between the node in front and itself increases. Emergency braking will cause an instant increase in the transmission range to the highest possible and a subsequent flooding of EEBL/R/A packets.

In the case where the node is the clustertail, it will behave similarly to the clusterhead. If there are any cars behind the node, the node will be aware because any new node closing in on the group will have a high transmission range. The clustertail will also vary its transmission range with its velocity. However, if it detects a node approaching the cluster from behind then it will extend it transmission range in order to send the acknowledgement packet to the approaching vehicle.

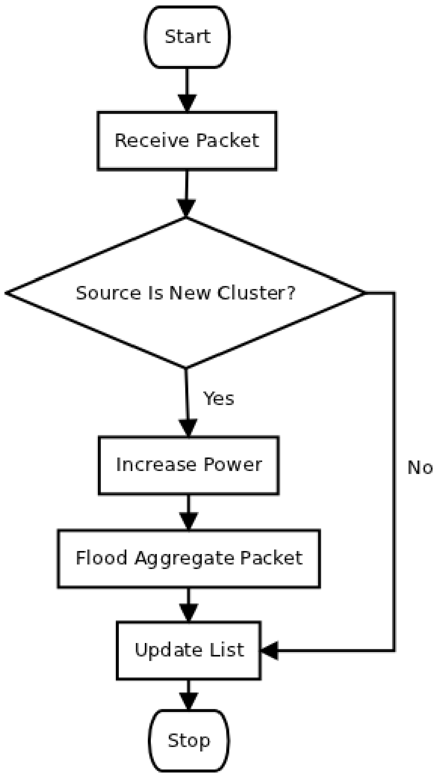

Figure 3.3: Flowchart of Acknowledgement Broadcasting Algorithm

Chapter 4

Performance Evaluation

4.1 Simulation Setup

The simulation of our system model was performed using the ns-3 network simulator on a UNIX system. For our simulation, a specific highway scenario was designed and the simulation was carried out on this scenario.

The scenario created was one of a stretch highway where two clusters of cars drive towards each other. More specifically, we created two clusters of nodes. The size of the clusters were 5, 10, 20, 30, and 40 on different runs of the simulation. The head of each cluster were placed initially $1000m$ apart. The nodes of each cluster in each lane were separated by a distance of $30m$. This scenario was used to simulate the effects of our clustering mechanism on the overall reception rate of the nodes. The simulation was run with normal transmission powers and with the altered transmission powers according to our protocol.

The scenario described above was used again to simulate the results of our transmission adaptation protocol described in Figure 3.2. To elaborate, the second scenario was used to observe the effects of the transmission range of the cluster head on the safety time and the overall reception rate of the nodes. This scenario was run using cluster size of 20 nodes over a two-lane highway at various transmission ranges of the head. The transmission range of the member nodes of each cluster had a transmission range of $8dBm$ following the range provided by our protocol (which is enough to transmit only to the immediate neighbor of each node). The simulation was performed at cluster driving speeds of $10ms^{-}$, $15ms^{-}$, and $20ms^{-}$.

4.2 Simulation Parameters

The full list of simulation parameters is given in Table 4.1.

Simulation duration	500 packets
Number of member nodes	5, 10, 20, 30, 40
Number of clusters	2
Driver reaction time	0.5 s
Packet size	400 bytes
Transmission Power	8, 16 dBm
Packet Generation Rate	10 packets/s
Decelaration	7 ms^{-2}

Table 4.1: Simulation Parameters

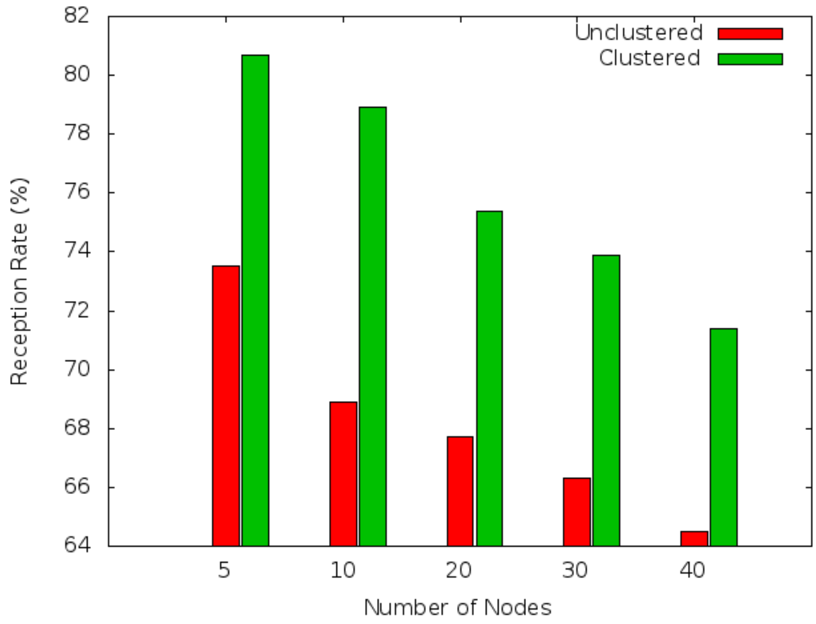

Figure 4.1: Effects of Clustering on Reception Rate

4.3 Simulation Results

Figures 4.1-4.3 show the simulation results for our highway scenario. Figure 4.1 is a bar graph that shows the results for out first highway simulation scenario. This shows the data that compares the effects of our clustering protocol. The x-axis shows the number of nodes in each cluster. The y-axis shows the overall reception rate for total number of nodes. The main results we can observe from this graph are that the size of the cluster decreases the reception rate and that clustering can improve the reception rate. The highest reception rate is seen with clustering with 5 nodes. This scenario has above 80% reception rate. Meanwhile without clustering we experience the lowest reception rate of about 64%.

Figure 4.2 shows the results for the second highway simulation scenario. This graph shows the results for the effect of the head transmission range on the safety time that the car has before there is not enough time to avoid a collision. The x-axis shows the value of the transmission range for the head of each cluster. The y-axis shows the value of the safety time that the cluster head receives. The significant effect we can notice in this graph is that as the transmission range of the head increases then the safety time allowed to the driver also increases. It is obvious from the graph the we have the greatest safety times at lower speeds than at high speeds.

Figure 4.3 also shows the results for the second highway simulation scenario. However this graph shows the results for the effects of the transmission range of the head on the overall reception rates for the nodes in the clusters. The x-axis here again shows the value of the transmission range for the head of each cluster. The y-axis show the value of the reception rate. The main result observed in this graph is that an increase in transmission range of the head decreases the total reception rate of the nodes.

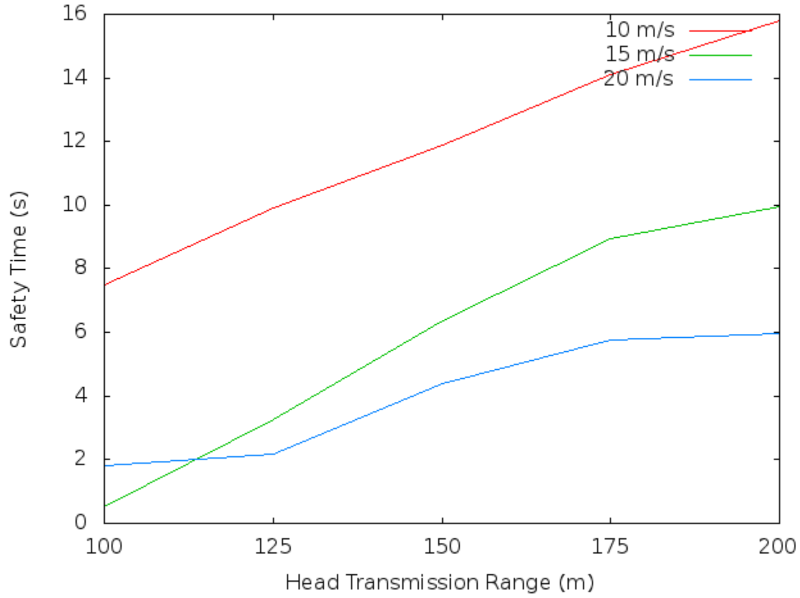

Figure 4.2: Effects of Transmission Range on Safety Time

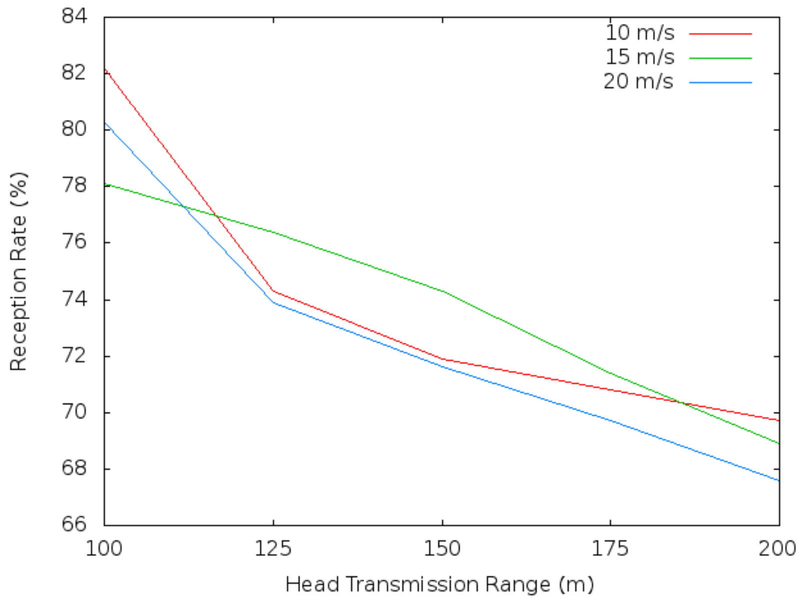

Figure 4.3: Effects of Transmission Range on Reception Rate

4.4 Impact of Clustering

From Figure 4.1, we can observe that the highest reception rates occur when clustering occurs. However, from the graphs, it may also be noted that the improvement in the reception rate does not seem to be significant. That is because the simulated scenario assumes that there is no channel degradation from the factors affecting visibility. In reality, these factors such as dense fog and, especially, torrential rains will have significant effects on the channel quality and greatly reduce the reception rate. So clustering will prove valuable in practical situations. To explain why clustering increases the reception rate, it can be stated that our clustering protocol results in member nodes only broadcasting to immediate neighbors. Therefore, there will be a great reduction in the interference of packets that is brought about by all the members broadcasting over great distances instead of short range.

4.5 Impact of Altering Head Transmission Range

Using graphs from Figure 4.2 and 4.3, we can analyze the effects the effects of altering the transmission range of the head of each cluster. From the graph in Figure 4.2, we can improve the safety time given to each driver by increasing the head's transmission range. The reason for this is that a warning packet will be sent or received earlier on than at a lower transmission range. On the other hand, an decreasing the transmission range also results in the improvement of the reception rate. As mentioned in the previous section, that small improvement in reception rate does not seem to justify reducing the transmission range. However, also as stated previously, in practical situations torrential rains may significantly reduce the reception rate and the already decrease the transmission range. Furthermore, the installation of safety applications on vehicles would inspire drivers to drive at faster speeds than they would without the applications. Therefore, there will be a small safety time in which to receive the warning packet and so reducing the transmission range practical siutations would increase the probability of receiving a packet within the safety time.

Chapter 5

Conclusion

5.1 Summary

Our work provides a wholistic approach to describe the communication requirements of VANETs in order to use safety applications in low-visibility conditions. It describes the functioning of the MAC layer to provide the necessary broacasting mechanism. A clustering scheme is also illustrated that improves transmission reception ratios. Lastly, we describe an algorithm which utilizes the information from the application level and creates changes on the physical level. Specifically, information about a node's velocity changes the maximum range at which it broadcasts packets. The algorithm is designed to adapt the transmission range to optimize safety time and delay reduction.

5.2 Further Work

Although we design several mechanisms necessary to design safety applications specifically for a low-visibility scenario, there are still areas that we need to cover and other scenarios that we can investigate in the future.

Our work, thus far, provides a design of the mechanism and algorithms necessary and supplies an intuition of how it functions. However, driver behavior can be more accurately modeled. To improve the accuracy of the results, a more realistic and precise driver's behavior modeling could be implemented.

The approach also assumes the low-visibility situations are created by environmental factors that have no or negligible effects on the transmission channel. That is, the conditions such as rain or fog play no role in channel degradation. In reality, rain will affect channel quality and future work could investigate the implementation of our system under such conditions.

Furthermore, our proposed concept can be used to give the drivers assistance while taking sharp turns in highways. When the visibility is low it is hard for drivers to take sharp turns because they are unaware of them. If the drivers can be warned a few seconds earlier before taking the turn then it will surely reduce the risk to some extent. For this purpose introduction of static infrastructure nodes could extend the improvement of the proposed system.

For example, if there is a static infrastructure node at a sharp turn with a fixed transmission range it can then help to notify the drivers about the turn. The transmission range of the infrastructure node should be optimal in order to provide the drivers enough time for making the turn. However, too large range can increase packet collision which is not desirable.

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