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Throughput optimization in DSRC for collision avoidance

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Abstract— As a standard way of moving vehicles' communication, VANETs (Vehicular Networks) have been characterized with enormous ability to increase the effectiveness of traffic and enhance the safety of cars on roads. Connected vehicle technology aims at dealing with important road transportation issues that concern environment and safety. Vehicular network density varies depending on the traffic load which can be high in the city, or low in suburban areas. The research provided a realistic analysis of the DSRC performance for varying vehicle densities over physical areas for urban and highway traffic using data packet response times and throughput as parameters. The Packet Delivery Ratio, the ratio of successfully received packets to the total number of packets sent, helps examine the hidden terminal effect on the communication using multi-lane traffic simulations for highway and urban scenarios. Computer simulations were done for 20, 40, 80 and 150 communication nodes for each traffic scenario; urban and highway to observe the effect of varying vehicle densities on the vehicular network communication performance. DSRC performance was studied for the traffic while analyzing the changes in the control parameters. We then proposed a control algorithm that secured data packets to address transmission errors resulting from the possible hidden node problem by improving packet throughput and controlling transmission delay. The algorithm minimizes packet losses resulting from possible collisions by giving an improved number of processes completed per unit time (throughput) for an increasing packet rate and effectively controlling the delay. Traffic simulation was done using a combination of SUMO (Simulation of Urban Mobility), OMNeT++ and VEINS for varying vehicle densities.

Index Terms — Collision avaoidance, DSRC, error control, packet delivery ratio, throughput, V2V, VANET

1 INTRODUCTION

Vehicular networks have attracted a lot of study interest in recent years. Road safety systems have been researched on and studies carried out to prevent road accidents or reduce the accident effects [1]. Vehicles and Road Side Units are communication nodes which have the ability to communicate and provide information in a bid to avoid traffic congestion that could lead to accidents. Dedicated Short Range Communications need to be as error free as possible in order to fulfil their safety-of-life objective. Vehicular networks use CSMA/CA, where transmission by communication nodes is done after sensing an idle channel [2].

Collision avoidance attempts channel division in almost equal proportions among the nodes transmitting in a communication range. In order for vehicles to share their broadcast information, they need to create an ad-hoc network, which requires a reliable low-latency vehicle-to-vehicle (V2V) communication that can handle firm rates. This requires fast and efficient V2V wireless communication, at 'data rates between 1 and 10 Mb/s' [3]. V2X's mobility of the wireless channels involved greatly affects the data packet throughput and response times. 'In US, 7.5 MHz spectrum [5.850-5.925 GHz] is allocated for DSRC', one of the key wireless technologies for Vehicular Networking. 'DSRC/WAVE operates in 5.9 GHz band (U.S) and 5.8GHz band (Japan, Europe) and has 75 MHz bandwidth allocated for vehicle communication, and range is up to 1 Km with vehicle speed of up to 140 Km/h' [4], [5]. Active safety applications need high levels of link reliability, interoperability, security and privacy. They require largely error-free performance. Vehicle-to-vehicle (V2V) communication that uses DSRC is estimated to be able to prevent up to 82% of car crashes in the United States, saving many lives and money [5].

The Uganda Bureau of Statistics report 2015 indicates 17,848 accident victims due to road vehicle crashes from 2014, which was a significant rise of 3% from the 2013 numbers [6]. The third Global status report on road safety, notes that low income countries and the middle income ones have fatality rates that are double the number in countries with high income and also have 90% of the global traffic deaths on roads which are the main cause of preventable deaths [7],[8].

The MAC layer of DSRC uses carrier sense multiple access

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with collision avoidance, whose wireless LANs' performance reduces when the shared channel gets saturated [9]. While DSRC device usage has been recommended as a highly promising technology in provision of robust vehicular communication ability, alone it's not sufficient to solve the traffic collisions because lots of factors need consideration, though it is definitely useful and its application requires it to be at its best performance. Collision is referring to the instance where more than one vehicle are at the exact same place at the same time instant often resulting in property and/ human damage. In VANETS, reliability refers to the ability to have sent messages or data packets get to their rightful destinations in the specified period of time.

The goal of this research was to perform error control for transmission of data using DSRC technology with the help of an algorithm that controls delay and maintains reliable throughput. The study devised means to improve the vehicular communication's reliability for both the highway and urban scenarios by effective transmission parameter control. We study the Packet Delivery Ratio (PDR) for different scenarios.

2 REVIEW OF PREVIOUS WORKS

This section reviews the works that have been done by researchers in effort to reduce errors in Vehicular Ad hoc Networks for Dedicated Short Range Communication and the hidden node problem.

2.1 Vehicular communications

Error control in for safety application in Vehicular communications has been studied by several researchers across the globe. Vehicle safety has been understood to need to be more than the old-style safety technologies like seatbelts and airbags.

[10] used V2V communication with DSRC to link vehicles through several technologies that are complementary for keen connectivity. Three models were applied to study V2V communication; the Stop-Sign, the Throughput-Enhancement Model and the Throughput-Enhancement Model with Agreement (TEMA). The proposed V2V- based protocols can manage intersections with minimum infrastructural reliance. The study however assumes an error free environment which is ideal.

[11] studied impact of the hidden node problem on transmissions, proposed increase of transmitting power from the nodes to enable non-hidden nodes detect hidden nodes by letting the range round each node increase in size, to include all other nodes yet [12] identified vehicles' interference as a major reason for loss of packets. Increasing transmission power may not work well for mobile nodes in the presence of obstacles.

[13] proposed ACORE (Algorithm for COllision waRning Error correction), an error correction algorithm to improve performance of Forward Collision Warning (FCW) applications using location information from GPS receiver to calculate safe braking distance from a vehicle moving towards a stationary vehicle. Experimental results showed reduced efficiency & reliability of application without ACORE. Experiments were conducted at speeds of 30, 40, 50 & 60 km/h with a GPS update rate of 5 Hz so the algorithm performance was not evaluated at higher speeds.

Zhang et.al [14] using field trials designed a prototype for "a DSRC-Actuated Traffic Lights system" that considerably lowered commute time and the travel time. The system operates with a low rate of penetration for the DSRC-equipped cars making it possible where a percentage of the vehicles have the devices installed. The study provided reliable information for the possibility of intelligent intersections with reduced delays in vehicle movement; but did not look at collision possibilities due to possible device errors.

Several studies have been done and are still ongoing, for different areas and scenarios, on Vehicular Adhoc Networks. The need to continuously improve reliability of mobile networks is still on and more so for safety applications in order to ensure no loss of lives. Error reduction is key in these research studies and more so for the wireless communication for DSRC safety applications and this is our study focus.

2.2 Hidden node problem

Traffic flow and efficiency is one of the major issues in cities with traffic jam and accidents being key shortcomings that greatly affect daily lives of the city dwellers. Studies have revealed that with DSRC deployment in VANETs, there has been considerable development in the transport sector's safety. However, being wireless communication with Access Points (APs), it is affected by the hidden terminal problem. While losses in VANETs can result from interference coming from nodes that are not hidden terminals, the hidden terminals have a great impact too. In VANETs, most applications are based on broadcast transmission [15]. Path losses and fading channels in these highly mobile nodes can increase chances of hidden terminals which are a major problem in mobile communications. The hidden terminal effect illustrated in Figure 1 is associated with an increased number of collisions in message transmissions [16]. The hidden terminal problem refers to when two or more terminals are outside the interference range of one another, as for nodes A and B, but share some terminals (C) that are within their transmission range for which they can cause collisions.

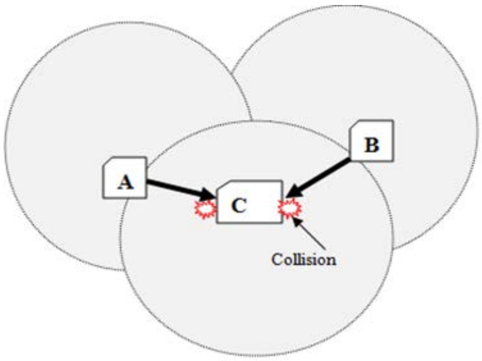

Fig. 1. Illustration of the Hidden node problem

Communication range can be illustrated with the intersecting regions and refers to the shortest radius around a transmitter that circumscribes all expected receivers.

A set of nodes R_N within a communication range R_C of the node N at a time t can be described as

$$R_N = \{i \mid \| \mathbf{x}_i - \mathbf{x}_N \| \le R_C\},$$

where $\mathbf{x}_N$ and $\mathbf{x}_i$ are locations of nodes *N* and *i* respectively.

Nodes in R_N are the expected receivers of the transmitted communication.

When the four conditions below are met, the node *m* is referred to as a hidden node when node *k* is transmitting to receiver node *p*

i) Node *k* is transmitting.
ii) Node *p* is not transmitting
iii) Node *p* is an intended receiver of *k* and *m.*
iv) *m* is not an intended receiver of *k*

Inaccurate sensing of a channel as free often leads to message collisions that cause message or packet loss and affects the packet response times and throughput.

2.3 The SUMO simulator

SUMO refers to Simulation of Urban Mobility. SUMO is an open source traffic simulator with a main feature of not allowing the duplication of vehicles since each vehicle has a unique id that cannot be duplicated [17], [18] . Tracefiles are created and used to describe communication nodes movement and SUMO is usually joined to an external communication simulator and SUMO's output is usually converted into formats the specific communication simulator understands [19]. Traffic Control Interface (TraCI) is found to control SUMO activity where the route formation, vehicular communication and controlling by TraCI on SUMO activity can be seen in phases.

[18] proposed a re-routing mechanism that updated the routes of vehicles dynamically during the simulation runtime in order to prevent the delay experienced by the occurrence of arbitrary road accidents. The travel time increase was reduced by this mechanism by an average of 35%. The study however needed to increase the dynamism of the re-routing. Real-world networks are presented as graphs and roads as edges. The traffic lights may overrule the right of way rules. Edges have a fixed number of lanes and have connections that are unidirectional. In addition to road network views, the road networks in SUMO include inter-lane connections across intersections which tell lanes that can be used to reach a subsequent lane.

3 METHODOLOGY

3.1 Simulators

A combination of traffic mobility simulator, SUMO, Network simulator, OMNeT++, and VEINS was used to configure a four lane road for the city (Kampala-Jinja road for slow heavy traffic) and semi-urban area (Kampala-Masaka high way, particularly Busega roundabout to Nabbingo for fast light traffic).

TCP connections between SUMO and OMNeT++ were managed by a python script provided by the VEINS module framework and are run in the mingwenv command line window. The script was started by running */c/Users/A/src/veins-veins-4.7.1/sumo-launchd.py -vv -c /c/Users/A/src/sumo-0.30.0/bin/sumo.gui.exe* in the command line window. The sumo-launchd is run with '-c' to be able to stipulate the command that should be executed to run SUMO and the '-v' to increase the verbosity of sumo-launchd. Veins scenarios are then simulated in the OMNeT++ IDE by right clicking on *omnetpp.ini* in the..*veins-veins-4.7.1/examples/veins* directory; then choosing *Run As > OMNeT++ simulation.*

3.2 Importing road networks

OpenStreetMap is used to import maps for use with SUMO which will simulate the topologies. OpenStreetMap is a free map and editable across the globe with no legal restrictions, hence conveniently available.

1) *Map scenarios from OpenStreetMap*

Urban Scenario

Maps for both Urban and highway scenarios are exported from OpenStreet Map. From https://www.openstreetmap.org, this scenario is from Kampala city in Uganda as extracted from the OpenStreetMap [20]. This is particularly part of Kampala-Jinja road, a 4 lane road in Kampala district, with intense slow traffic most times of the day.

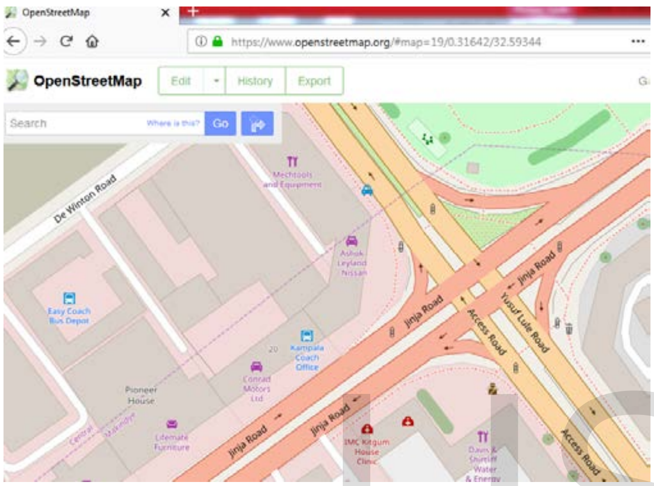

Fig. 2. Kampala-Jinja urban road scenario

To be able to convert each of the maps into a road network understood by SUMO, in the console the netconvert command is run, *netconvert --osm-files map.osm -o map.net.xml*

Polygons are added by copying additional polygons from https://sumo.dlr.de/wiki/Networks/Import/OpenStreetMap and saving them in a notepad editor as a typemap.xml file

In order to show the map rightly in SUMO the polyconvert command below is run in the console.

polyconvert --net-file map.net.xml --osm-files map.osm --type-file typemap.xml –o map.poly.xml

This call to polyconvert imports different polygons from OpenStreetMap data and converts them into appropriate visualizations for SUMO-GUI producing a Sumo-polygon file and making the map complete for usage by SUMO.

3.3 Random routes generation in SUMO

RandomTrips.py is a python script developed in order to produce random routes. Random routes are one of the methods used to generate traffic demand in SUMO.

The command below is run in the console while in the sumo\bin folder.

D:\UON\omnetpp5.1\sumo\sumo-0.30.0\tools\randomTrips.py --net-file map.net.xml --route-file map.rou.xml --begin 0 --end 100 –length.

A **sumo-launchd.py** python script manages TCP connections between SUMO and OMNeT++. It uses the command *c/Users/A/src/veins-veins-4.7.1/sumo-launchd.py -vv -c /c/Users/A/src/sumo-0.30.0/bin/sumo.gui.exe* which is run in the command line. The resulting output on the command line is *Listening on port 9999.*

SUMO GUI simulation

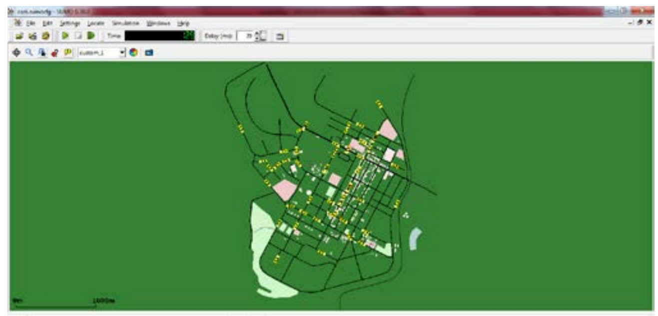

Fig. 3. Urban scenario simulation in SUMO interface

Fig. 4. Highway scenario simulation in SUMO interface

4 RESULTS PRESENTATION & DISCUSSIONS

This section presents results from the research and discusses them. The research study considered urban and highway scenarios; where the urban vehicles are slow moving and intense for a given area and highway vehicles are fast and fewer for a given area. The communicating vehicle nodes studied were 20, 40, 80 and 150 for both scenarios.

4.1 Initial simulation results

TABLE I
RESULTS FOR NODES IN THE URBAN SCENARIO

Number of nodes	20 nodes	40 nodes	80 nodes	150 nodes
Sent packets	50	100	200	375
Received packets	50	81	149.2	279
Delay (ms)	1.51	2.27	2.38	3.34
% Lost packets	0	19	25.4	25.6
% Reached nodes	91	93.4	96.7	98

TABLE II

RESULTS FOR NODES IN THE HIGHWAY SCENARIO

Number of nodes	20 nodes	40 nodes	80 nodes	150 nodes
Sent packets	50	100	200	375
Received packets	50	80	101	171
Delay (ms)	1.09	2.21	2.36	3.36
% Lost packets	0	20	49.5	54.4
% Reached nodes	100	99	99	97

4.2 Study of Sent packets, received packets, delay, percentage of lost packets and percentage of reached nodes for 20 communicating nodes, 40, 80 and 150.

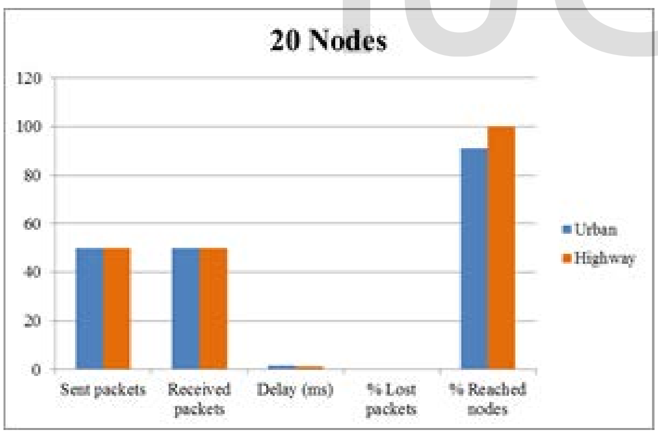

Fig. 5. Results for transmission with 20 nodes

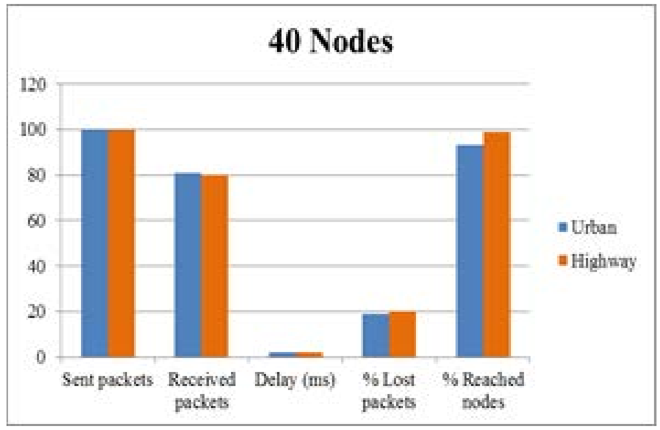

Fig. 6. Results for transmission with 40 nodes

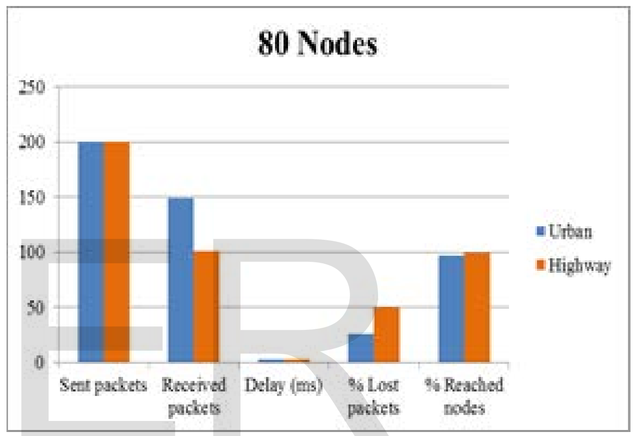

Fig. 7. Results for transmission with 80 nodes

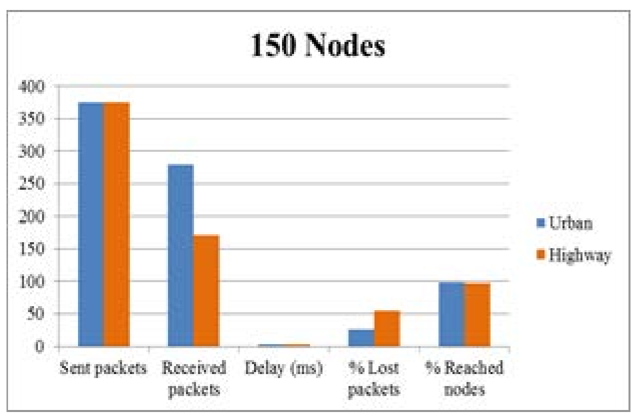

Fig. 8. Results for transmission with 150 nodes

Figures 5 to 8 above generalize the packet reception and loss probabilities for both urban and highway scenarios for all considered node numbers. An example is the percentage of lost packets for 80 nodes in the urban scenario is 25.4 which is much higher than 0% for 20 nodes. Increasing vehicle numbers generally affect the number of received packets. The urban scenarios studied had more road lanes, and with increasing cars, chances of collisions are high due to increased transmissions. With the RTS/CTS mechanism, the packets in queue increase for increasing vehicles. Increased packets in queue lead to higher chances of channel over load and packet drops. The increasing number of sent packets is seen to increase the delay for both scenarios. The highway vehicles sense fewer nodes in their communication range and that can slow down transmission as the sender waits for an available node. Some nodes may be available but hidden to the transmitting nodes hence higher chances of packet collisions with an overall vehicle density increase. Reached nodes are less affected in the highway scenario than in urban scenario. In general, for both scenarios, an increase in communicating nodes lowers the overall communication network performance. Vehicles outside the communication range in question will usually miss out on receiving data packets and that increases the unreachable nodes. This is more significant for a highway scenario.

It can therefore be concluded that an increase in node number degrades network performance; and yet with the growing study on Vehicular Networks with DSRC usage, and the increasing traffic intensity in the nations, we will not do away with an increase in numbers of nodes so we must deal with the situation by devising means of managing maximum reliable data transmission with minimum error.

4.3 Proposed algorithm flow

Step 1: Start
Step 2: Send RTS
Step 3: Receive CTS
Step 4: Forward message packet
Step 5: Receive ACK from destination.
Step 6: Count Number of ACKs received.
Step 7: If (ACKs < expected min)
  Identify missing ACKs
  Else
  Proceed with transmissions
Step 8: Determine number of drops.
Step 9: If (drop > safe value)
  Apply algorithm to secure packets
  Else
  Continue transmissions.
Step 10: End.

4.4 Algorithm simulation results

This section discusses the results of the simulations in presence of the the algorithm for improved DSRC performance. The algorithm was implemented in Java IDE on an Intel Core i7, 2.5GHz PC with 8GB memory. Urban, intense slow traffic and highway light fast traffic were the scenarios studied.

TABLE III
RESULTS FOR NODES IN THE URBAN SCENARIO WITH ALGORITHM

Number of nodes	**20 nodes**	**40 nodes**	**80 nodes**	**50 nodes**
Sent packets	50	100	200	375
Received packets	50	95	190	367
Delay (ms)	1.01	1.23	1.31	1.32
% Lost packets	0	2	7	15

TABLE IV
RESULTS FOR NODES IN THE HIGHWAY SCENARIO WITH ALGORITHM

Number of nodes	**20 nodes**	**40 nodes**	**80 nodes**	**150 nodes**
Sent packets	50	100	200	375
Received packets	50	94	188	369
Delay (ms)	1.05	1.21	1.32	1.34
% Lost packets	0	3	11	23

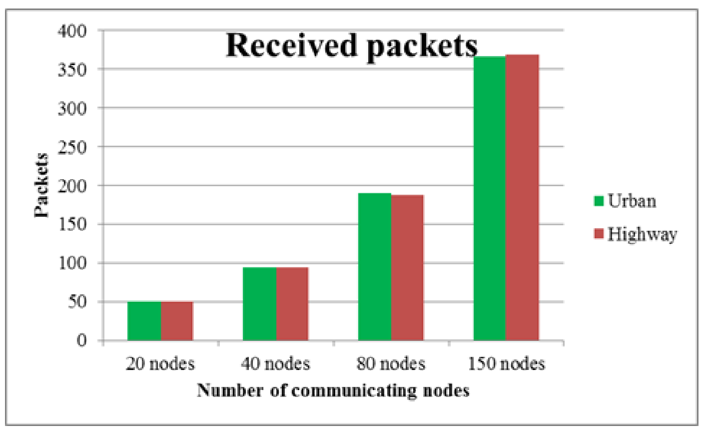

Fig. 9. Received packets for Urban and Highway scenarios with algorithm.

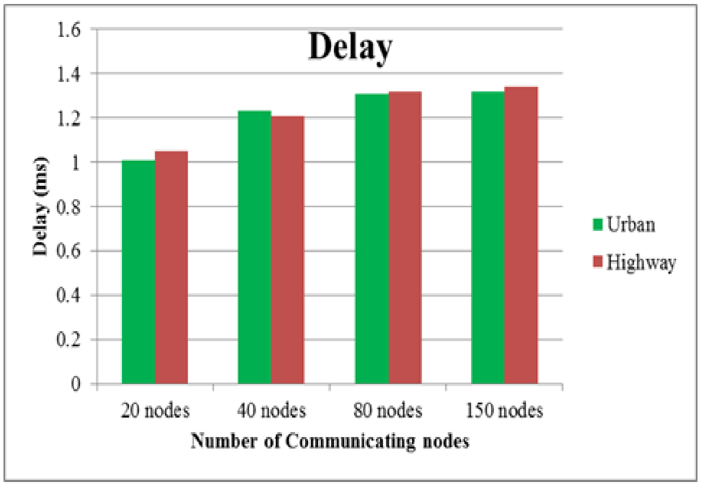

Fig. 10. Delay variations with algorithm.

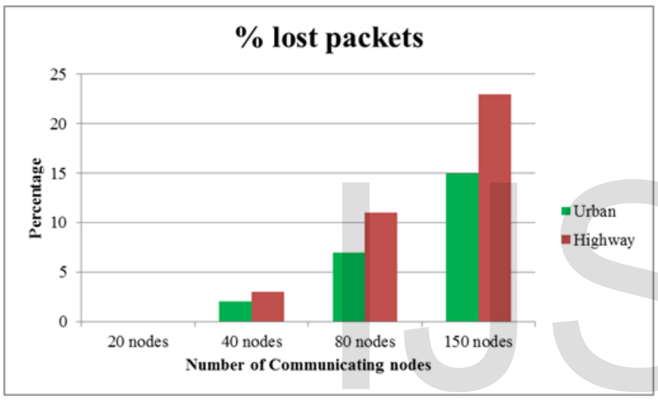

Fig. 11. Percentage number of lost packets with algorithm

Number of received packets in presence of the algorithm is seen to generally increase for both the urban and highway scenarios as seen in figure 9. Packet delay as illustrated in figure 10 is greatly reduced and has a very small variation for varying vehicle densities. Percentage packet loss is zero for very few communicating nodes, a case of 20 nodes, and gradually increases for increasing vehicle density as shown in figure 11 though it remains very low with algorithm implementation than without the algorithm. Throughput in presence of algorithm is increasing even with higher vehicle densities as illustrated in figure 12 below. The algorithm's ability to secure data packets over the increasing channel load makes it possible to have a throughput increase while the delay is lowered contained about a constant value. The study assumed that the real world data was exact and SUMO accurately portrayed real life situations for the traffic movement.

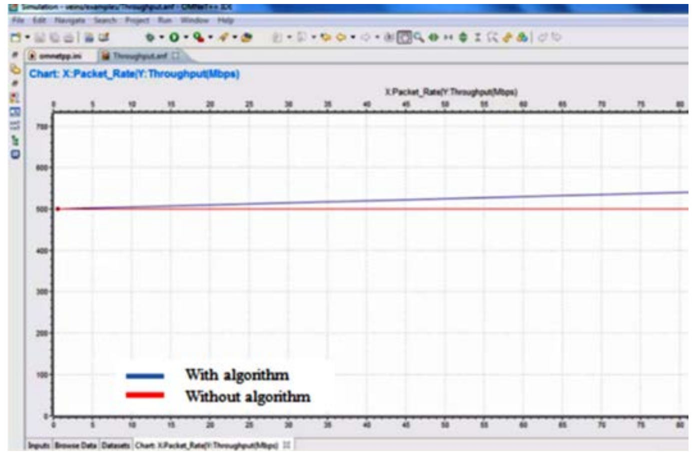

Fig. 12. Throughput optimization.

5 Conclusion

Automated wireless vehicles are a reality and vehicle-to-vehicle interactions will soon be practical in different nations. Dedicated Short Range Communication remains a strong and preferred support for the Vehicular Adhoc networks. Being wireless communications, the operation is not without error which can be internal or external and yet for safety applications, error-free communication remains the goal of the several studies. On-going and further studies continue to aim at communication with as little error and possible and at improving DSRC technology because of its high regard in the hope to improve vehicular communications.

Error control is critical in the urban centers given the high vehicle density and higher chances of transmission interferences and for highway vehicles (nodes) as well because we don't want to waste transmission bandwidth. We propose a simple error control mechanism to control packet losses and delays based on intervehicle interactions with focus on two scenarios (urban and highway). We studied the impact of vehicle density on intervehicle communication performance. Lost packets increase with increasing vehicle densities implying there is need to control the channel load for traffic in order to increase communication reliability. The study proposed an error control algorithm that secures packets to lower chances of loss due to delay in order to lower its effect on throughput. Message delivery is more effective hence lower chances of collision. DSRC's quality of service must get better in order to achieve full ability to carry out the safety-of-life mission.

For future research studies, it will be of good help to have joint software that singly and automatically installs VEINS on different operating systems. OMNeT++ and SUMO version compatibility brought issues during configuration of VEINS.

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