Performance Evaluation of IEEE 802.11p for Vehicular Traffic Congestion Control

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Abstract— Vehicular traffic congestion in metropolitan cities during disaster is a challenge which presents dire consequences for transporting VIPs, life saving drugs, patients, accident victims in need of immediate medical assistance etc. With better navigation system and real-time traffic congestion updates, the vehicles can overcome delays. Vehicular Ad Hoc Network (VANETs), transmits the real time congestion information to the vehicles from a centralized database to avoid unexpected congestion and follow the shortest path to the destination. In this paper a proposed prototype which can be modified to work for the requirement with different models, such as general traffic prediction and re-routing during emergencies in case of fire, accidents etc. along the route is worked out. IEEE 802.11p which has been introduced exclusively for vehicular environments has been implemented at the Physical and Medium Access Control (MAC) layers of the WAVE protocol stack which was considered for a metropolitan city over an unpredictable high density of vehicles. Evaluation of the performance of IEEE 802.11p, Wireless Access for Vehicular Environment (WAVE) communication standard against IEEE802.11a for the vehicular environment for multiple scenarios has been simulated and the results are encouraging.

Index Terms— AODV, inter- vehicle communication, ns-2, SINR, urban environment, VANETs, vehicular traffic congestion, WAVE, 802.11p.

1 Introduction

Traffic congestion is formed by many factors; some are predictable during road construction, rush hour or bottle- necks and some are unpredictable due to accidents, natural calamities, weather and human behavior there by Drivers, unaware of congestion ahead eventually join it and increase the severity of it. The more severe the congestion is, the more time is consumed to clear once the cause of it is eliminated or ameliorated. Efficient city planning and traffic management can reduce congestion to some extent. Widening of roads, creating one ways, installing traffic lights at specific crossroads, controlling these lights so they best allow vehicles through and strict traffic laws can curb congestion. The vehicles themselves must be able to communicate with each other and tackle congestion where in the Vehicular Ad-Hoc Networks (VANET) come in.

VANETs[1] are a special kind of mobile Ad-hoc networks (MANET) which aim at achieving intelligent inter-vehicle communications, seamless Internet connectivity resulting in improved road safety, essential alerts and accessing entertainment and news. Vehicles are designated as nodes in a vehicular ad-hoc network (VANET) along with the access points to determine the current traffic conditions distributed over long distances through Vehicle-to-Vehicle (V2V) communications and related information is broadcasted to neighboring vehicles by multiple hops. Vehicle-to- Infrastructure (fixed access points, nodes) communication provides a high bandwidth link between nodes. The roadside access points are placed every kilometer or less, enabling high data rates to be maintained during heavy traffic. Wireless access in Vehicular Environments (WAVE) standard is used for the communication between V2V and V2I (all nodes).

2 Related Work

2.1 VANETS

The main goal of VANET is providing safety and comfort for passengers. Collision warning, Road signal alarms and in place traffic view will give the driver essential tool to decide the best path along the way. VANET or Intelligent Vehicular Ad-Hoc Networking provides an intelligent way of using vehicular networking. Recent research efforts have placed a strong emphasis on novel VANET design architectures and implementations. A lot of VANET research work has focused on specific areas including routing, broadcasting, Quality of Service (QoS), and security.

Specific Characteristics of VANET:

1) Highly Dynamic topology.
2) Frequently disconnected Network.
3) Mobility Modeling and Prediction.
4) Communication Environment.
5) Hard Delay Constraints.

6) Interaction with on-board sensors.

Although countless number of routing protocols has been developed in MANETs, many do not apply well to VANETs. VANETs represent a particularly challenging class of MANETs. VANETs found application in controlling the high density vehicles and managing the traffic during congestion in metropolitan cities[2]. They are distributed, self-organizing communication networks formed by moving vehicles, and are thus characterized by very high node mobility and limited degrees of freedom in mobility patterns[1]. The importance of VANETs in Intersection Collision Warning Systems is the cars exchange status information and predict collision[3].

In order to evaluate the performance of VANET systems various consortia and projects have been undertaken[4]. Various protocols and architecture have been developed and tested. Different simulators for testing of VANETs have been explored[1]. Qualnet[5] is a tool for network simulation that is used for wired and wireless packet networks. Several well known network protocols are provided. The organization of the various elements are as per the OSI model. It is the commercial successor of GloMoSim. It can be used to both design and optimize networks. Grafling et al.[6] have evaluated the performance of the IEEE 1609 and

802.11p protocols in Qualnet. The WAVE multichannel operation as per the IEEE 1609.4 has also been implemented by modification and extension of existing protocols. The mobility mechanisms[12] are complex due to unpredictable factors like frequent changes in one-way permits, presence of disturbances and traffic violators. We shall consider these factors in a better mobility model in the future.

2.2 WAVE

Wireless connectivity between moving vehicles can be provided by existing 802.11a compliant devices with data rates of up to 54 Mbps being achieved with 802.11a hardware. However, vehicular traffic scenarios have greater challenges than fixed wireless networks, caused by varying driving speeds, traffic patterns, and driving environments. Traditional IEEE 802.11 Media Access Control (MAC) operations suffer from significant overheads when used in vehicular scenarios. The IEEE 802.11a PHY employs 64-subcarrier OFDM, out of these 52 are used for actual transmission consisting of 48 data sub-carriers and 4 pilot sub-carriers. The pilot signals are used for tracing the frequency offset and phase noise. The data bits are coded and interleaved before modulating them onto the sub-carriers to combat fading problems . IEEE 802.11p[7, 8] PHY has the same specifications as IEEE 802.11a except for the following changes:

1) The Channel Bandwidth is scaled from 20MHz to 10MHz to increase the delay spread tolerance introduced by the vehicle mobility.

2) Operating frequency bands for IEEE 802.11p is 5..9 GHz American ITS band. The 75 MHz is divided into seven 10 MHz channels and a safety mar in of 5 MHz at the lower end of the band. The center channel is the control channel, on which all safety relevant messages are broadcasted. The remaining lower priority communication is carried on the remaining channels known as service channels,

3) four classes of maximum allowable Effective Isotropic Radiated Power (EIRP) up to 44.8 dBm (30W) are defined in IEEE 802.11p. This can be used to support different communication ranges for the vehicles,

4) 802.11p uses 10MHz frequency bandwidth, that reduces the effects of Doppler spread and

5) the double guard bands used reduces the Inter Symbol Interference caused by multi-path propagation doubling the symbol length and making the signal more robust against fading.

802.11p is an IEEE standard that defines enhancements to 802.11 to support Intelligent Transportation Systems (ITS) applications in the context of Intelligent Transportation Systems (ITS), vehicle to-vehicle (V2V) and vehicle to infrastructure communications (V2I) that are being developed, namely the DSRC (Dedicated Short Range Communications) operating in 5.9 GHz band. WAVE is likely to become a standard that can be universally adopted across the world compared to the regional standards of DSRC. At present DSRC based on the Wi-Fi standard is widely used in VANETs as it connects infrastructure to vehicle and also vehicle-to- vehicle using two way short range radios which is of lower costs compared to other wireless standards available[9].

The Federal Communications Commission (FCC) has allocated 75 MHz of spectrum at 5.9 GHz that is used by IEEE 802.11p Wireless Access in Vehicular Environments (WAVE), Fig.1[10] and dedicated short-range communications (DSRC) chipsets, capable of providing coverage for a range of one thousand kilometers and works with a 10 MHz channel spacing, data rates ranging from 6 to 27 Mbps depending upon the modulation techniques used.

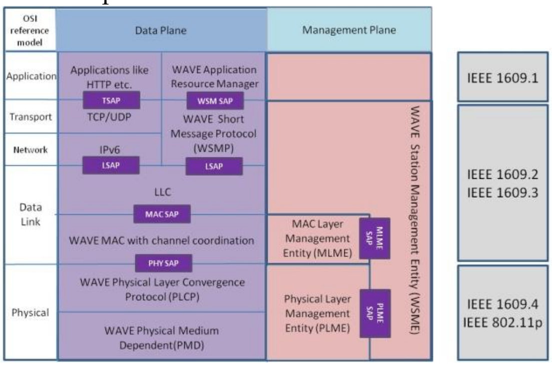


Fig. 1. WAVE Communication Stack

WAVE defines two types of devices: RoadSide Unit (RSU), and OnBoard Unit (OBU) which are essentially stationary and mobile devices respectively. RSUs and OBUs can be either a provider or a user of services that can switch between such modes. Normally stationary WAVE devices host an application which provides a different service compared to mobile device that hosts a peer application. WAVE standard describes applications that resides on the RSU but is designed

to multiplex requests from remote applications thus providing them with access to the OBU. WAVE uses Orthogonal Frequency Division Multiplexing (OFDM) to split the signal into several narrowband channels to provide a data payload communication capability of multiples of 3 upto 27 Mbps in 10 MHz channels.

MAC addresses are assigned a random value initially, as and when an OBU receives a message from another OBU or RSU, a new MAC address is assigned. MAC layer also implements IEEE P1609.4, which is a Multi-Channel operation standard and determines the behavior of MAC layer on the available control channel (CCH) for safety communication and Service channel (SCH). The messages can be transferred using Internet Protocol Version 6 (IPv6) or Wave Short Message Protocol (WSMP) that employs Non-IP based application for high priority messages. The WSMP block in the stack is a provider and the channels at the edges are reserved for future use to avoid accidents with channel 178 as the control channel while the remaining ones are service channels.

2.3 NS-2

Ns-2 is an accepted tool for network simulation, since, its architecture is suitable for extensions and interfacing with other simulation modules and implemented using IEEE 802.11 protocol. Further this has been extended to include additional parameters to simulate the IEEE 802.11p[11]. Ns-2 also features a simple model for the representation of reflections, refraction and shadowing effects caused by buildings and other obstructions

3 Proposed Work

3.1 INTRODUCTION

By equipping vehicles with communication devices we can effectively turn them into data collectors. Distributed applications can be implemented over this infrastructure to detect congestion and propagate congestion information to future vehicles enroute to the congestion area making it possible for the driver to seek alternate routes to avoid the congestion. Congestion detection algorithms are designed to detect areas of high traffic density and low speeds. Each node captures and disseminates information such as location and speed and processes the information received from other nodes in the network.

The exchange of information among vehicles in a particular geographic area requires reliable and scalable communication capabilities using the appropriate protocols in the Physical and MAC layers. The MAC layer provides access to contention based and contention-free traffic on different kinds of physical layers. MAC layer is further divided into the MAC Sub layer and MAC management sub-layer. The former defines the access mechanisms and packet formats while the latter defines power management, security and roaming services. The PHY layer handles building packets for different physical layer technologies, modulation and coding techniques and also manages issues like channel tuning.

The layers above the Data Link Layer follow the standard OSI model. AODV routing protocol is used for simulation and the routes are constructed only when desired by the source nodes that are maintained as long as they are required which can even form trees to connect members of multicast group. It is loop-free, self-starting, and scales to large numbers of mobile nodes. It is observed that as the number of nodes is increased the performance of AODV also increases.

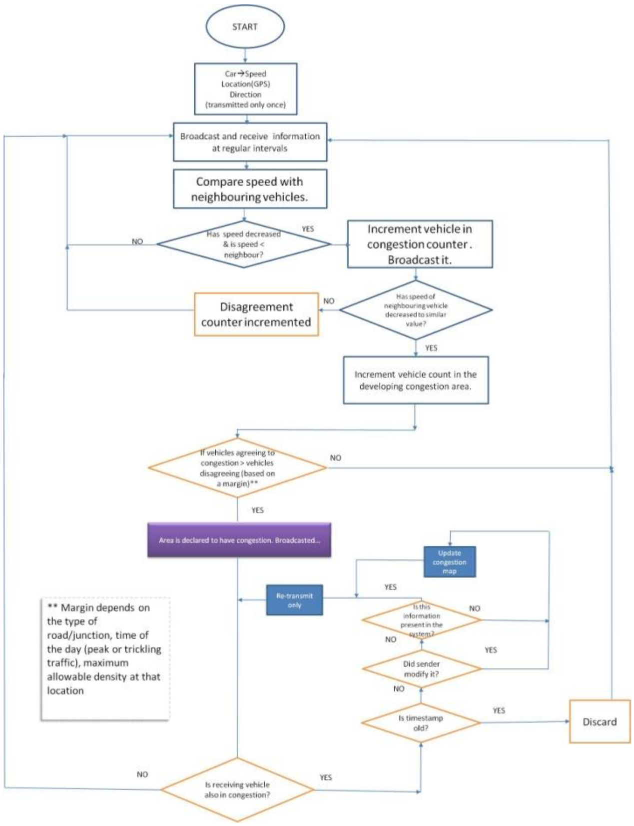


Fig. 2. Congestion Detection Algorithm Flowchart

3.2 CONGESTION DETECTION ALGORITHM

The congestion detection algorithm works on the application layer with vehicle parameters derived from a Global Positioning System (GPS) device. The congestion map is built when large clusters of slow moving nodes are determined and the information may be stored and retrieved from a centralized system or passed on normally from vehicle to vehicle. Road-Side Unit(RSU), the Passive unit(repeater) is deployed to transmit data during blind spots along which vehicles would not traverse or obstacles being present restricting propagation of signal where in there is a demand from the centralised location at any instant to perform other intelligent operations. The information thus obtained can be presented to the driver on the existing On-Board Units (OBUs) or via text messages, variable signboards, LCD displays etc.

The information may be transferred to GPS display devices on the vehicles themselves to graphically present traffic data to the driver. The main parameters used for the vehicles are the speed, location , direction, type of road/junction, time of the day and allowable vehicular density of the roads in the algorithm. All vehicles(nodes) are GPS enabled to read the parameters and broadcast to the neighbouring vehicles(nodes). Periodically the node updates the speed of its neighbouring nodes to predict a possible congestion and transfers this information. If the nodes around these are not moving at a slower speed than this node, they increment a counter to indicate the number of vehicles moving normally. In case the neighbouring vehicle agrees with the congestion state of the initialising vehicle, a congestion counter is incremented and as the value exceeds the normal moving vehicles values by a certain predefined limit, then congestion is confirmed. Vehicle receiving any information checks its own status for congestion and proceeds else it updates and transmits congestion information into the geographical map with a flag indicating modified information by the immediate sender.

Several security concerns must be addressed to prevent misuse of this system. For instance, creating a false congestion on the map by a node injecting malicious information into the system may lead to the drivers avoiding a particular route that would favour individual or group. A single node participating in such behaviour by injecting single set of variables or consolidated congestion data, tend to get overridden by the other nodes containing valid data. There is a need to prevent the tracking of individual vehicles when they transmit data to protect privacy.

Correction of position related information can also be achieved by this system. If a certain node is unable to access GPS data, its position and other necessary information can be obtained from the available data by sharing with the surrounding vehicles and/or RSUs.

In addition to the real time data of the moving vehicles, the congestion information is refined by the use of preexisting data in the form of the current road or junction at which the vehicle is located, the time of the day and the maximum road traffic junction allowable at that location. Certain junctions and roads may be more prone to traffic congestions due to location of certain principle institutions. Peak hours is considered from the inflow of traffic due to the presence of the mentioned institutions or organisations which influence the traffic density. The last parameter is the inherent road capacity which on being exceeded almost certainly leads to traffic congestions. These factors can be used to map to determine congestion more accurately. Holiday seasons, festivals and other such events are also considered to estimate traffic congestion and its variations in density.

Once such data has been collected over a certain period, the traffic congestion maps at different locations and times of the day can be predicted with good accuracy.

3.3 MOBILITY CONSIDERATIONS AND PROPAGATION RANGE

Considering urban scenario the density of vehicles is very high. In Bengaluru, INDIA, the vehicle to capacity ratio of significant roads ranges from 1.52 to 3.62. The vehicles are packed in tight groups and have a highly restricted path. With existing traffic regulation mechanisms like traffic signals etc. in place, clustering of vehicles is frequent and in large numbers. In our simulation results 802.11a works better at lower speeds. Considering the high vehicular density, the slight drop in throughput and increase in end-to-end delay 802.11p is highly reliable due to stable topology and improved routing efficiency.

3.4 IMPLEMENTATION ON THE WAVE STACK

Implementing on the Physical and MAC layers of the WAVE stack which is defined by IEEE 802.11p enables the units to interact in a dynamic environment without the need for joining a Basic Service Set(BSS) or within a WAVE BSS. The MAC layer defines the signaling techniques and interface functions. The 1609 family of standards for WAVE provide architecture and a complementary, standardized set of services and interfaces for communication between vehicles. A multi-channel scheme is followed at the MAC layer. The channels are divided into a Control Channels (CCH) and multiple Service Channels (SCH)[13]. The CCH is used to transmit WSMP to exchange safety information and also to announce WAVE services, while SCH is used for commercial application interactions and data transmissions. The PHY layer has seven 10MHz channels in the 5.9GHz band.

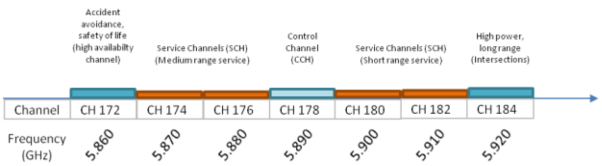


Fig. 3. 802.11p channels

The Existing 802.11 models for the PHY layer has limitations on range and also the maximum data rates achievable. 802.11a has several shortcomings in a vehicular environment due to varying vehicular velocities and crowded environments. This is due to its tendency to be absorbed by obstacles. On the other hand PHY layer of 802.11p is modeled to suit the peculiar characteristics of the vehicular radio channel. It has adopted Orthogonal Frequency Division Multiplexing(OFDM) modulation technique and is capable of achieving different data rates as mentioned. OFDM is a spread spectrum scheme which splits the data into parallel streams and carried on orthogonal sub-carriers. Different coding and modulation schemes have been defined for these sub-carriers. The required modulation technique can be selected by choosing the appropriate index value for the basic modulationscheme_ parameter. The broadcast will be transmitted with the selected modulation scheme while control packets (RTS/CTS/ACK) will always be transmitted with the basic modulation scheme.

TABLE 1

802.11P PARAMETERS

Parameters	IEEE 802.11p
Supported data rates (Mbps)	3, 4.5 , 6, 9, 12, 18,24
Modulation Schemes	BPSK, QPSK, 16-QAM, 64-QAM
Coding rate	1/2 , 1/3, 3/4
No. of Subcarriers	52 (48+4)
Symbol Duration	8μs
FFT Period	6.4μ
Guard time	1.6μs
Preamble duration	32μs
Subcarrier frequency spacing	0.15625MHz

TABLE 2

802.11A PARAMETERS

Parameters	IEEE 802.11a
Supported data rates (Mbps)	6, 9, 12, 18, 24, 36, 48 and 54
Modulation Schemes	BPSK, QPSK, 16-QAM, 64-QAM
Coding rate	1/2 , 1/3, 3/4
No. of Subcarriers	52 (48+4)
Symbol Duration	4μs
FFT Period	3.2μ
Guard time	0.8μs
Preamble duration	16μs
Subcarrier frequency spacing	0.3125MHz

The 802.11p standard has been simulated with parameters provided by IEEE 802-11Ext Patch 2. The WirelessPhyExt and the Mac-802_11Ext are inherited from the WirelessPhy and Mac-802_11 classes separating the PHY and MAC functionalities. The parameter CSThresh value is only used as the threshold above which the medium is indicated as BUSY to the MAC layer, and not any longer as a threshold that has to be exceeded in order to receive a packet. The capture capability allows the frame header and body to be distinguished as one may use different modulation schemes for the two. The MAC data is transmitted with higher modulation scheme than the header (usually BPSK).The capture technology is effective in enhancing reception capabilities for vehicular communications as the IEEE802.11 device may be able to detect and choose a frame with a stronger header signal.

A steady value greater than the Signal to Interference Noise Ratio (SINR) has to be maintained throughout the packet reception period for the successful arrival of the packet. The Nakagami RF model gives the general model of a radio channel with fading and can closely represent a wireless channel. The WirelessPhyExt also allows us to trace the drop packets. To enable this tracing phyTrace On command line has been included in node-config of the tcl script. Results show that the number of dropped packets in 802.11p is much lower compared to 802.11a at higher velocities.

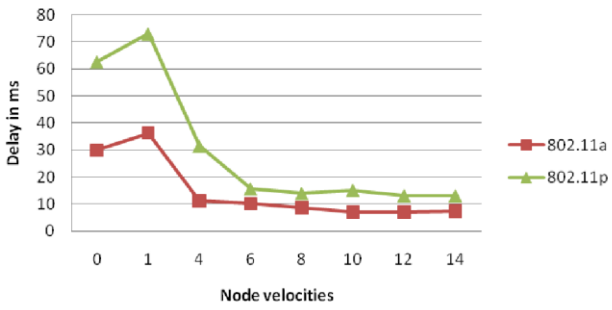


Fig. 4. Average end-to-end delay

4 Simulation and Results

The simulation was carried out on ns-2 with parameters for both 802.11a and 802.11p and was compared for end-to- end delay, throughput, packet drops during various modes. The range of velocities of the nodes is considered from still vehicles (0m/s) to that of vehicles in the urban environment (14 m/s). The required statistical data can be extracted from the trace file using the AWK programming language.

TABLE 3

Simulation Parameters Considered

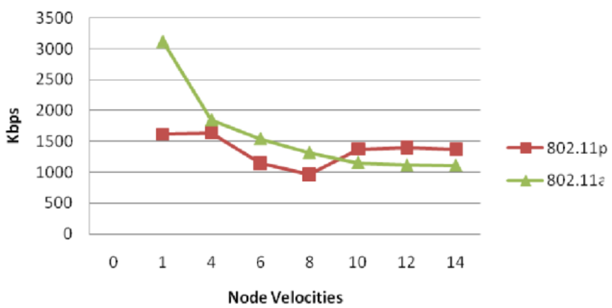
Parameters	Values
Simulator	NS2
No. of mobile nodes	5
Simulation time	200s
Node speed	0 to 14m/s
Area of topography	700 X 700
Routing Algorithm	AODV
Traces	Agent, MAC , PHY
CBR Packet Size	512

The graphs may be explained as follows:

1) End to end delay: The end to end delay (in ms) is higher (60 ms) in the case of 802.11p than 802.11a (30ms) initially. It decreases with increasing velocity. The end-to-end delay for 802.11p approaches that of 802.11a at higher velocities and saturates. Since the difference between the two is in the order of 4ms, it is concluded that this does not have a significant impact on performance, Fig. 4.

2) Throughput: The average throughput for 802.11p is initially lower than that of 11a. It increases at velocities in m/s close to nominal vehicular speeds in the urban environment i.e. 8 m/s. This is in agreement with our argument, Fig. 5.

Fig. 5. Average throughput



3) Packet Delivery fraction(PDF): The packet delivery fraction (PDF) shows a similar trend and reaches a steady value of 0.92 for velocities higher than 8 m/s for 11p , fig. 6.

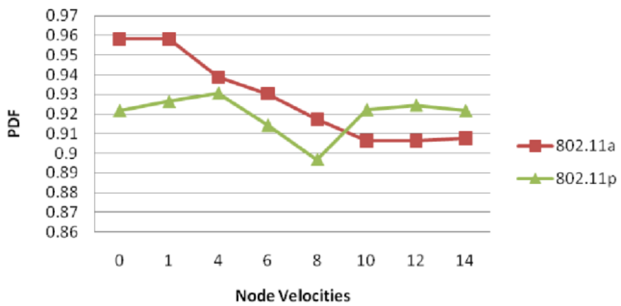


Fig. 6. Packet Delivery Fraction (PDF)

The next set of graphs that are plotted represent the values of the conditions due to which packets were dropped and the packets lost due to various scheduling related events, fig 7 through 11, which are agreeable for highly dynamic scenarios wherein there is an improved performance at higher speeds.

These are logged by setting the option phyTrace to ON under node configuration using the following code format in the TCL script of the simulation.

```
$ns node-config
.
.
-macTrace OFF
-phyTrace ON
```

There are two conditions for dropping of packets:

(a) The reception power is lower than the carrier sensing threshold or insufficient for the preamble being received without interference (PND).

(b) The reception power is higher than the carrier sense threshold and sufficient to decode the data, but the packet is dropped due to a scheduling related event. These include SXB, TXB, RXB, PXB and INT.

These graphs represent the No. of packets dropped vs. the node velocities in m/s.

1) TXB: This parameter indicates the number of packets dropped when the PHY is busy transmitting a frame. The number of drops are higher for 11a until the velocity of 10 m/s, the difference between the drops is smaller for higher values of velocity, Fig.7

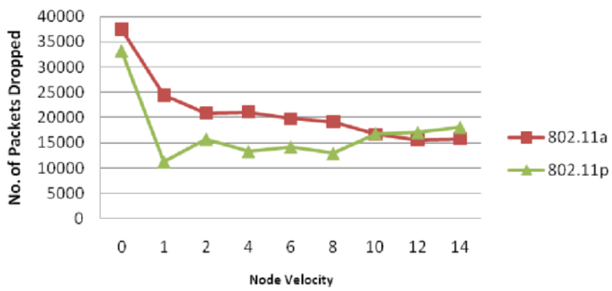


Fig. 7. Packets dropped when the PHY is busy transmitting a frame (TXB)

2) SXB: This indicates the no. of packets dropped when the PHY interface is idle and is searching for a valid preamble. The values of packet drops coincide for velocities from 2 m/s to 12 m/s. Since the increase in packet drops increases very slightly for higher values of velocity for 11p, this can be deemed acceptable, Fig. 8.

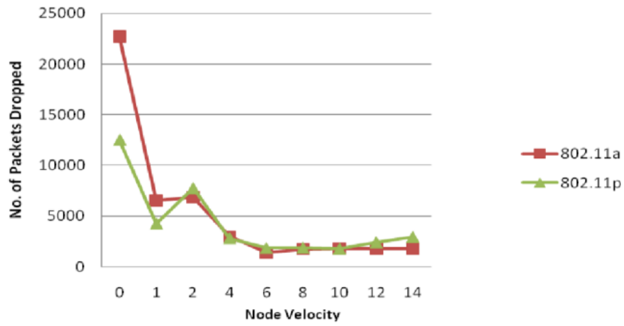


Fig. 8. Packets dropped when PHY interface is idle and searching for a preamble

3) PXB: The number of packets dropped when the PHY is receiving frame preamble. The dropped packets are lower in the case of 802.11p for velocities higher than 6 m/s, Fig. 9.

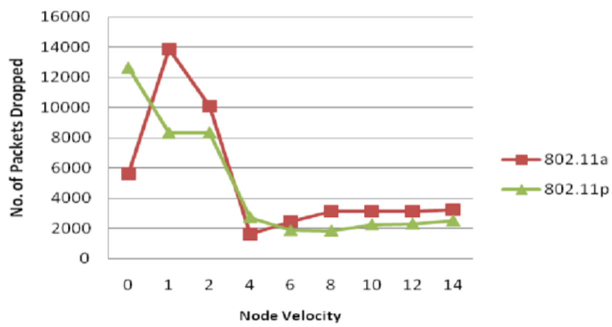


Fig.9. Packets dropped when PHY is receiving a frame preamble

4) RXB: The number of packets dropped when the PHY is busy receiving a frame. This parameter shows a dip in the No. of packets dropped at 4 m/s and is almost equal (11p being slightly lower than 11a) for higher velocities, Fig. 10.

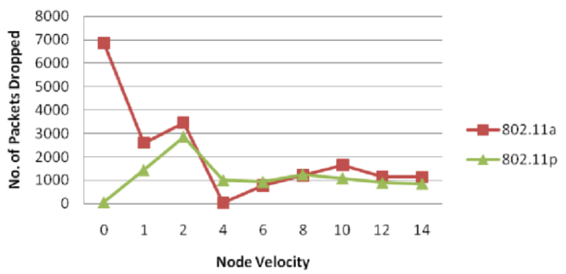


Fig. 10. Packets dropped when PHY is busy receiving a frame

5) INT: This parameter indicates MAC interruptions. The transmission of a control frame, like an ACK or CTS frame, is of higher priority than the ongoing transmission due to which MAC forces the abortion of the current reception. This value is lower than 6 for velocities greater than 4 m/s for both the protocols, Fig. 11.

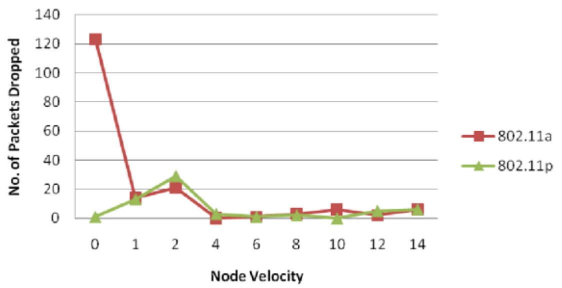


Fig.11. Packets dropped due to MAC interruptions

6) PND: PND indicates that reception power is lower than the carrier sensing threshold or not enough for preamble being received even without any interference. The graph for the number of dropped packets falls for both 802.11a and p from 0 till they get equalized at a velocity of 8 m/s. There are fewer packets dropped in case of 802.11a beyond this, but the difference may be reduced by suitably changing the power thresholds, Fig 12.

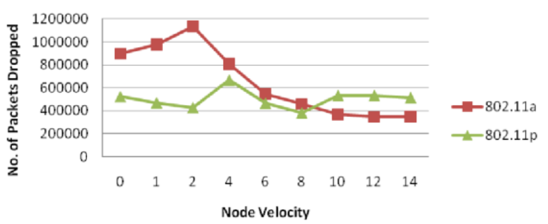


Fig. 12. Packets dropped when reception power is lower than the carrier sensing threshold or not enough for preamble being received even without any interference

Packets dropped as the reception power was lower than the threshold for carrier sensing or lack of suitable preamble reception in the absence of interference for which value of lost messages is plotted for the same values of Preamble Capture Threshold (4dB), fig. 12. Although there is a nominal overhead due to lost packets in 802.11p at higher speeds, this can be adjusted by suitably varying the capture threshold. A similar argument may apply for the number of SXB events. The various packet drops at the PHY layer that are logged also show a superior performance of 802.11p is an encouraging trend.

5 Conclusion

It is conclusively proved that, during the present scenario, 802.11p works better on the MAC and Physical layers than 802.11a. The proposed Vehicular congestion detection Algorithm would work at the application layer. Further work will be on incorporating the 1609 standard into the implemented stack and experiment with different vehicular traffic scenario. In an urban scenario this system works best while considering different factors such as vehicular density and clustering. Using this system as a basis, it finds applications in several other areas such as Emergency services, Virtual Busways and General traffic management and rerouting.

The proposed system also finds application where traffic congestion is detected by the vehicles and the information can be shared with the ambulances through a central base system which simulates to fix priority routes for the driver carrying accident victims, patients etc., find shortest path, minimum travelling time thereby avoiding congested routes.

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