Simulation and Analysis of Vehicular Adhoc Network with TDMA using SUMO and NS3

Karanbir Singh Gill
1102263
kgill7@lakeheadu.ca

Khushal Paresh Thaker
1106937
kparesh@lakeheadu.ca

Vinit Krishnankutty
1096016
krishnankuttyv@lakeheadu.ca

Dhairya Patel
1115318
dpatel99@lakeheadu.ca

Alizar Marchawala
1103258
amarchaw@lakeheadu.ca

Supervised by,
Dr. Dariush Ebrahimi
Lakehead University

***Abstract*—Applications relating to Vehicular Ad hoc network (VANET) are an emerging and promising sector in the Intelligent Transportation System (ITS). Real time communication and high reliability are paramount for such applications. To support real time communication, predictable and timely access to the channel is a must. Efficient broadcast services for such applications in VANET are provided by Medium Access protocol. High mobility and rapid topology alterations represent a highly dynamic nature of VANETs which downgrade the existing Medium Access Control (MAC) protocol performance. In this paper, we use Time Division Multiple Access (TDMA) and Signal to Noise Ratio (SNR) to remove any interference from simultaneous transmissions and allow communication between nodes in a base station within a cluster respectively. Also, efficiency and fairness are considered to achieve maximum data rate and rightness. The proposed communication model has been simulated in SUMO and NS3 to analyse and gauge the performance.**

Keywords–VANET, TDMA, DSRC

I. Introduction

Vehicular Ad hoc NETs (VANETs) are designed mainly to increase road safety. They can also be used to boost conditions for traffic management and to provide infotainment on board, such as Internet connectivity, video streaming, etc. Communications may be between Vehicle To Vehicle (V2V) vehicles or between Vehicle To Infrastructure (V2I) vehicles and roadside units in VANETs. The V2V and V2I applications can be broken down into the following three services: security services, traffic management and user-oriented services. In terms of the standard of operation, security services have unique criteria. In VANETs, by using the same radio frequencies, the nodes share a common wireless channel, so incorrect use of the channel can lead to collisions and bandwidth waste.

MAC systems must be configured to securely and equally distribute the media between the various nodes. MAC protocols usually fall into one of two broad categories: contention-based and non-contention-based. Each node may try to access the channel when it has data to be transmitted using the carrier sensing mechanism in contention-based protocols.

A free channel can be sensed by many neighbouring nodes, so they decide to access and transmit their data at the same time, which causes collisions at the destination nodes. Contention-free MAC protocols aim to prevent this by assigning only one node in a neighborhood at any given time to access the channel. Contention-based protocols do not require any predefined schedule, and when it needs to be transmitted, each node can fight for channel access without any guarantee of success. This can cause issues such as packet loss or a significant access delay for real-time applications. Therefore there is a need to design a model in which channel efficiency is maintained, that is the full spectrum of available bandwidth should be utilized efficiently.

Dedicated Short-Range Communication (DSRC) is helpful in V2V and V2I communications supporting vehicle speeds to about 190 km/h and transmission range of 300 m. The frequency band is divided into 7 channels of 10 MHz which is further split into 6 service channels (SCH) and one control channel (CCH). The high priority and network management messages are transmitted via CCH.

II. Literature Review

Li et al. [1], proposes a novel approach to efficiently broadcast safety related services in distributed TDMA Based VANETs. The research makes use of two different regions: High perceptual quality region (HPQR), in which information regarding closeness to the vehicle range is real-time and accurately provided, Basic Perceptual quality region (BPQR), which provides a transmission range that includes the BPQR's boundary. A high transmission power P0 and low transmission power P1 is required for HPQR and BPQR respectively. A method is proposed wherein P0 and P1 are used alternatively by the knowledge of slots that are established by the nodes about their nodes as the transmission time is scheduled in MAC protocols based out of TDMA. The model has two kinds of merging collision: reconcilable (RMC) and irreconcilable merging collisions (IMC) which can be eliminated by using the neighbour nodes. IMC is classified further based on position and the node's moving direction by which they can collide. This model when tested showed major improvement in quality of awareness of remote vehicles in high density networks. Research also states that the performance of the network was widely improved using the approach.

An adaptive TDMA based MAC protocol for VANETs (VAT-MAC) is proposed by Cao et al. [2], where maximum time slot utilization is ensured by adjusting each frame of time frame length. The proposed protocol makes use of Road Side Units (RSU) that provides an estimation of the vehicles contesting for the available time slots and determining the optimal length to maximise the throughput. This makes sense to provide efficient broadcasting service using Node Estimation (NE), Leaving Node Determination (LND), newly entering node prediction and time frame optimization (NETF) technique. The protocol allow vehicles that avoids collision and successfully accesses a slot, to be provided with a slot in free transmission period (FTP).

NETF calculates vehicle density, optimizes subsequent frame lengths and predicts the nodes that would be entering. The proposed VAT-MAC performs better than other related protocols because of optimization of frame. Also, coordination overhead is better than others. To overcome the issue of vehicles having to drop most of its packets due to no channel access before generating the next message, Kotecha et al. [3], proposed a self organising time division multiple access (STDMA), a decentralized and predictable MAC protocol with finite access delay that better aids real-time ad-hoc vehicular network movements. The nodes that make use of STDMA algorithm have the capability of broadcasting messages contained in data messages from their position. The process is carried out in stages: initialization, network entry, first frame and continuous operation. STDMA needs the position information from other members of the network for it to work. When tested, the performance revealed significant reuse of slots and less data packet drops.

The scope of finding and creating a path with the support of TDMA [4] using clustering mechanism helps to put forward an efficient Quality of Service (QoS) approach for routing. QoS metric is analysed and the corresponding provision values of QoS are calculated. Followed by selection of a reliable, stable and optimal path between sender, cluster head and the intended receiver. Vehicular ad hoc network is highly recommended for an effective transportation system. There are several constraints while implementing VANET. So in order to reduce the end to end delay and assuring QoS in terms of throughput, propagation delay and the path stability, a suitable QoS protocol is needed. The research work proposes LORA – CBF based QoS protocol for routing designed for VANET.

An inter cluster communication is managed by the cluster head with the support of TDMA. In the proposed scheme, a cluster is formed by vehicles that move in the same direction and are in the similar transmission range. Every vehicle involved in the mechanism can be either a cluster head (CH), ordinary member or a gateway for the transmission of data. A node in the routing scheme is designed to be in one of the three modes which are transmitting mode, CH mode and receiving mode. Safety related messages are sent by the vehicles to the CH, the control messages on CCH are transmitted to the neighbouring nodes and the final destination by the CH. This effective communication among the neighbouring nodes helps to create an awareness about the slots which are un-allocated.

Long transmission power range is used by CH to share the information to the surrounding CHs. An upstream TDMA or an efficient downstream broadcasting approach is adopted by the CH if it desires to communicate with the CHs within the same cluster. The CH is responsible for allocating data channels for the cluster node members. For a safe data transfer, CH make use of the small slots for broadcasting the message from the framework of TDMA to CCH. The performance metrics used for evaluating the scheme are throughput, packet drop number, utilization of the channel. Throughput indicates the number of packets that the destination received from the total number of packets send. The number of packets which were lost or not obtained at the receiver is indicated by the packet drop. Without considering the throughput, channel utilisation refers to employment of the channel in the most efficient way.

In order to attain maximum bandwidth, TCP and UDP transmission protocols are used along with TDMA. An advanced TDMA based MAC protocol [5] is proposed for an optimized VANET communication scheme referred to as EVC – TDMA. Based on the buffer dimension and relative speed, the vehicles dynamically pick the relay access points for a Multi-hop data transmission. Based on the broadcast message sent, the other relay nodes can transmit the relay messages depending upon on the status of their own buffer. Markov process two dimension strategy is used as the base technique to examine the buffer length. Using EVC – TDMA helps to minimise rate of packet dropping and maximise throughput. The experimental set up was first performed and analysed on static networks, later real time parameters and variables were included related to VANET. Depending on the distance between the vehicles and the communication range, the neighbour nodes are classified into one and two hop nodes.

The channel for communication is divided into service channel and control channel. The control channel is used to send control messages and service channel send are set for non-safety associated applications. Since the nodes in a VANET commute frequently, a stable effective relay node is to be chosen for a Multi-hop communication. A cooperative node is the one which monitor and analyse the Multi-hop messages to gain Multi-hop relay and these nodes stay in the vicinity to the relay nodes. The cooperative transmissions are undertaken when the buffers are inert and they act based on two modes. The relaxed mode indicate the load in the transmission network is minimal and busy mode stipulate that the network load is high, hence the normal nodes can transmit only when the buffers are relaxed. For avoiding blocking with respect to head of buffer, the packets will be dropped at the buffer head by the corresponding node when the buffer is full.

Hadded et al. [8], proposed an adaptive TDMA based slot assignment technique to cluster vehicles for VANET. This research makes use of a MAC layer protocol in order to avoid using expensive spectrum and diminish the inter-cluster interference. This technique needs its cluster heads to transmit the frame information periodically to its 2 neighbouring cluster heads. Simulating the proposed technique shows that it achieves good reservation and time slots are utilised in a better way but aren't as good as other papers as mentioned in the future work.

The literature survey has proven useful as there were many researches being conducted in the field of wireless communication and more so towards communication in VANET. The concept of power transmission which is in the research by Li et al. [1], was quite interesting and so has been slightly modified and been accommodated in this project. Proposed communication model is different from Cao et al. [2], as the technique involved to allot time slots for vehicles is from RSUs in the research while frame information provided from cluster heads is used in this project. Kotecha et al. [2], makes use of self-organising TDMA while the proposed model isn't based on that. Also, the proposed communication model has a different approach to that of proposed in research [4] and [5]. The model takes into consideration the direction of vehicles moving while research by Hadded et al. [8], doesn't.

III. Problem Definition

VANETs are efficient networks that help with traffic safety. Vehicles can communicate with each other so as to avoid accidents. There are many protocols that aren't reliable due to the higher velocity of nodes, lack of infrastructure, etc. This paper tries to tackle the existing issues and propose a wireless communication model for a VANET wherein the objective is to maximize the amount of transmitted data and minimize the data loss.

IV. Problem Formulation

A. Solution Process

Figure 1 represents a schematic map with vehicles in intersections transmitting while figure 2 shows a screenshot of the simulation of the model at a time frame of 32 msc where vehicles have stopped. The methodology consists of few steps: firstly, the nodes should be grouped into different clusters. Because of high mobility in VANET routing the messages to their final destination are often a challenging task. Therefore VANET should consider the speed and velocity of vehicles or nodes to construct stable clusters. We will appropriately select the CH to cope with the communication among its cluster members. The advantage of using different clusters is that we are able to use the identical divided bandwidth for an additional cluster without fear about interference.

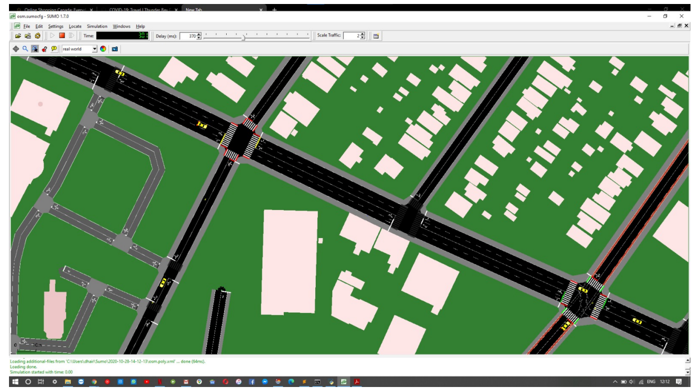

Fig. 1. Screenshot of the Schematic Map

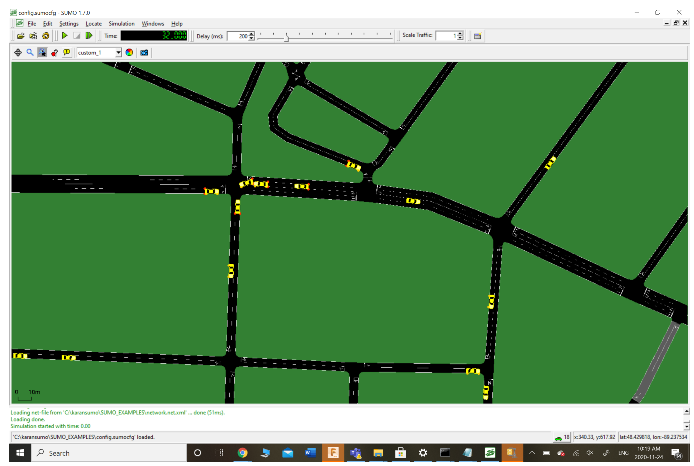

Fig. 2. Screenshot of Simulation at timeframe 32 msc

Available bandwidth is divided into orthogonal channels using Orthogonal Frequency Division Multiplexing (OFDM) which provides bandwidth scalability, career aggregation and low interference. The key benefit of OFDM over single-carrier systems is its ability to cope without complex equalisation filtering with extreme channel conditions (for example, attenuation of high frequencies in a long copper wire, narrow band interference and frequency-selective fading due to multi path). Channel equalisation is simplified because OFDM can be interpreted as using several narrow band signals that are slowly modulated rather than one wide band signal that is quickly modulated. The low symbol rate makes it economical to use a guard interval between symbols, making it possible to remove inter symbol interference (ISI) and use echoes and time-spreading (visible as ghosting and blurring in analogue television, respectively) to achieve a gain in variety, i.e. an increase in the signal-to - noise ratio.

As shown in the figure 3, cluster creation would be carried out and the available bandwidth would be split using OFDM. After that, to ensure that they can execute simultaneous transmissions, we need to compute signal to interference plus noise ratio (SINR) for each node. Data transmission and scheduling will then be carried out in the designated resource block. This

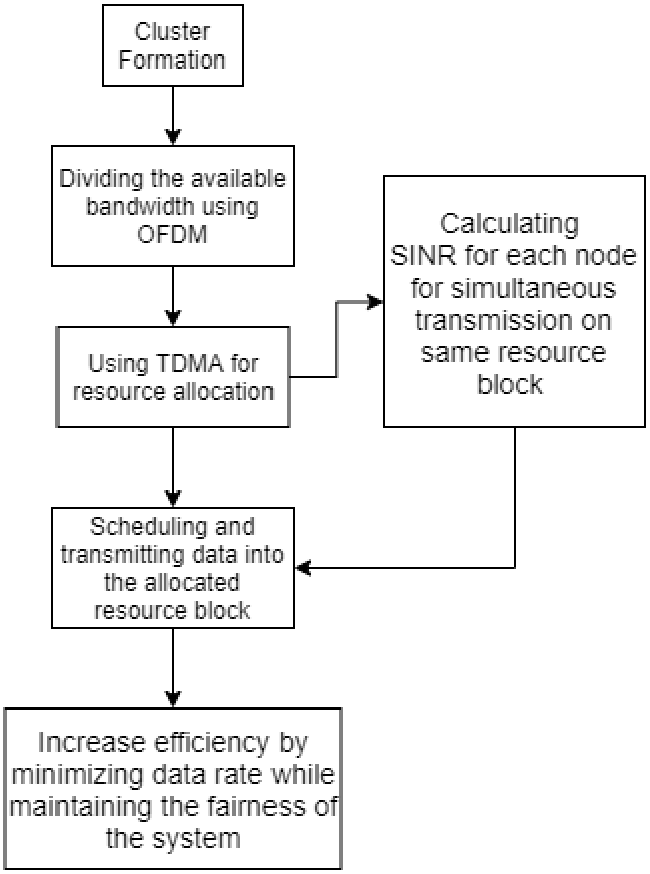

Fig. 3. Flowchart of the process

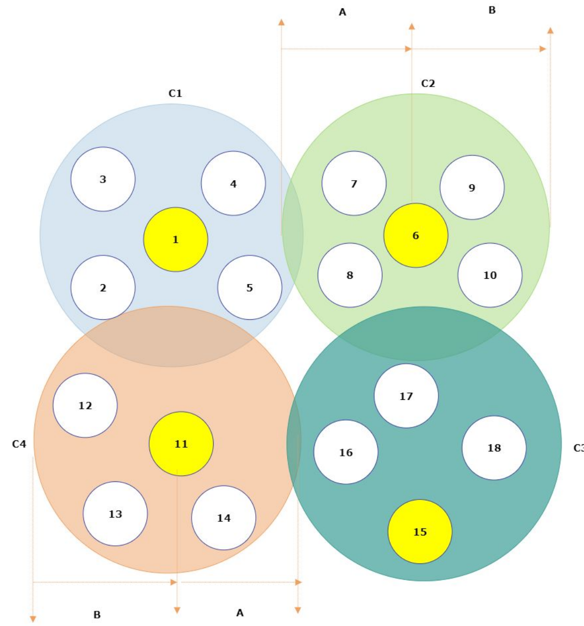

Fig. 4. Cluster Formation

methodology helps to optimise the performance by combining the aspects of minimising the data rate and acknowledging the system's fairness.

B. Cluster Formation

The algorithm to form clusters is based on the Euclidean distances of the vehicles position. In most of the researched algorithms to form clusters, the direction is not taken into consideration which leads to forming new clusters every time a vehicle moves opposite to the cluster head. The proposed algorithm is stabilised by considering the directions of vehicles travelling i.e., vehicles that travel in the same direction will be members of a cluster. Therefore, the range of transmission and calculated Euclidean distance will be used to decide clustering of vehicles. The position, speed and direction of each vehicle is broad casted to the one-hop neighbours after which a list containing the neighbours is created. Vehicle with least average distance, most dense neighbourhood of vehicles and speed similar to average speed is selected as the cluster head.

C. Slot Allocation

For a periodic time slot, a vehicle sends reservation request to the cluster head CH when it needs to access network. Once the request is received, depending on the direction in which the vehicle moves, it is provided with a first available slot from a subset of slots i.e., if vehicle is behind the cluster head, it is assigned a first available slot from 'B' subset of time slots and if vehicle is ahead of the cluster head, available time slots are allocated from the subset of time slots 'A' as shown in the cluster representation image in figure 4. The third category of time slots 'N', would be unused subset from the cluster where all vehicles are inactive. The cluster head distributes the time slots according to the MAP of the neighbouring clusters. Cluster Gateways (CG) help procure the information required about MAP of the neighbour clusters. Once a time slot is selected that has to be allocated, a reservation that includes an unique identifier is transmitted. The frame information is sent to both the cluster head neighbours through the Cluster Gateway. Information that would be inside the identifier would as follows:

- MAP{{A,B,N},{A,N,B} or {N,A,B}}
- Cluster head ID that can identify which cluster head sent the frame information
- Size of the A,B,N subset and also the state of each time slot with its moving direction

Information is transmitted once the size of the subsets are updated by the cluster heads. The cluster head will communicate with its neighbouring cluster heads to reserve a slot for the vehicle when time slots in A and B are not free, Also, to avoid interference issues within clusters, ordering is done and different for every neighbour. Having time slots allocated based on the movement and positions of the vehicle and utilizing a centralized, balanced approach, allocations are optimised and maintains fairness.

D. TDMA

TDMA-based MAC protocols are an evolving area of research in the field of VANETs, where time is divided into slots and only one vehicle can enter the channel at each time slot. In TDMA, all vehicles use the same frequency channel, but at a different time without any code sequence. This implies that the transmitter and the receiver must be synchronised with frequency. The TDMA technique guarantees that other simultaneous transmissions would not interfere with them. In addition, I2V communication can be effectively facilitated by TDMA, as fixed RSUs can be used to build and manage the TDMA slot reservation schedule. Another essential aspect of the TDMA system is that it enables multiple vehicles to assign a different number of time slots. We prefer TDMA over Code Division Multiple Access (CDMA) and Frequency Division Multiple Access (FDMA) because in FDMA to synchronize all the nodes we need to create a dedicated control channel frequency which is used by vehicles to negotiate frequencies by exchanging control messages. Also in CDMA there is a requirement of code assignment to negotiate and allocate codes for every communication which leads to additional significant communication overhead in both FDMA and CDMA techniques

To prevent any hidden terminal issue, the time slots used by all other vehicles within its one-hop neighbourhood must be included in the header field of each message transmitted. Thus each vehicle can decide the set of time slots used by all vehicles within its two-hop neighbourhood and the set of available time slots by reading the packet obtained from its one-hop neighbourhood. By randomly accessing every free time slot, it may attempt to obtain a time slot. The vendors centrally conduct the distribution of time slots to nodes on the service networks.

The provider is a vehicle that announces a service delivered on a particular service channel in the Announcement of Services (AnS) control channel area. The customer is a car that receives a service announcement and chooses to make use of the service. It is the duty of the operator to assign time slots to all customers and to announce this slot assignment to the service channel in unique time period considered the key slot of the provider. When the provider earns approval of the service in the Acceptance of Service (AcS) region, it tunes the second Transceiver to the same service channel and begins providing the service in the time slots declared in the AnS field.

E. Optimization

The optimization of scheduling is achieved by modelling it through mixed integer programming (MIP) and Linear Programming (LP) solution. The idea formulated for maximising the data transmission and minimizing data loss is by using compatible set (CS), which allows parallel and concurrent transmission under a stipulated interference [7]. To make sure that the simultaneous communication of multiple nodes with the base station are successful within a cluster, we calculate SINR. It is calculated by the following equation,

$$SINR_{tr} = \frac{p_t d_{tr}^{-\alpha}}{N + \Sigma_j p_j g_{jr}} \geq \beta \tag{1}$$

where,

$$t = Transmitter\ index$$

$$r = Receiver\ index$$

$$j = Simultaneous\ transmitter\ index$$

$$p_t = Transmit\ power$$

$$g_{tr} = d_{tr}^{-\alpha} = Channel\ gain$$

$$N = Noise\ power$$

$$\beta = Target\ SINR$$

$$d = Transmitter\ to\ receiver\ distance$$

$$\alpha = Path\ loss\ exponent\ (or\ path\ attenuation\ exponent)$$

Here if the SINR value is higher than the β (target SINR value) then only the simultaneous transmission will be successful. Here there is a fine trade off between power of signal of different nodes in a cluster competing for simultaneous communication. When a node is transmitting a signal to the base station, the power level of the node will be tuned accordingly to the interference of the nodes transmitting simultaneously over the same channel. When multiple nodes are transmitting simultaneously, then the value of SINR will be decreased. To adjust this situation, we need to increase the power level of the given node. This situation is called power control which is achieved by the feedback provided by the base station. Using the following equation, each mobile node updates its transmission power, and after some fluctuations, the transmission power converges to an optimal one.

$$P_i(t+1) = \frac{SINR^{Target}}{(SIR(t))} * P_i(t) \tag{2}$$

In scheduling the main objective is to maximize the data rate to fully utilise the channel. But, we also need to consider the transmission fairness which basically means that all the nodes need to get an equivalent chance to access the channel and transmit signal in the system. Here in simultaneous communication all the nodes will try to transmit the data at the maximum data rate. But if the channel only allows certain nodes to transmit into the channel because of their higher data rate. It would be a question of fairness because others might not get a chance to transmit. In order to get fairness instead of maximizing data rate, we can maximize the minimum of data rate for every device present in the cluster. So to achieve maximum data rate and fairness we need to consider the following situation,

$$Efficiency = max(\Sigma Ri)$$

$$Fairness = max(min(R1, R2, ..., Ri))$$

F. Metrics

There are many metrics based on which the performance of the communication model are measured. Few of them are:

1) Loss of Packets: Failure of successful packet transmission results in packet loss. Main reasons could be collision and a lower power signal. Packet loss can be calculated as the ratio of packets lost to the total packets transmitted.

2) Throughput: when a part of channel capacity is utilised to transmit data it is called as throughput. Aim of the research is to minimize the access delay and maximize the throughput.

3) Fairness: In a fixed time interval, fairness can be defined when all vehicle/units have equal access to a medium. Also, fairness is a measure of capability to distribute the bandwidth priority wise depending upon the traffic.

V. Simulation Results

To analyse the communication model proposed, simulations were conducted using SUMO and on NS3 simulator [9] and the framework of it is shown in figure 5.

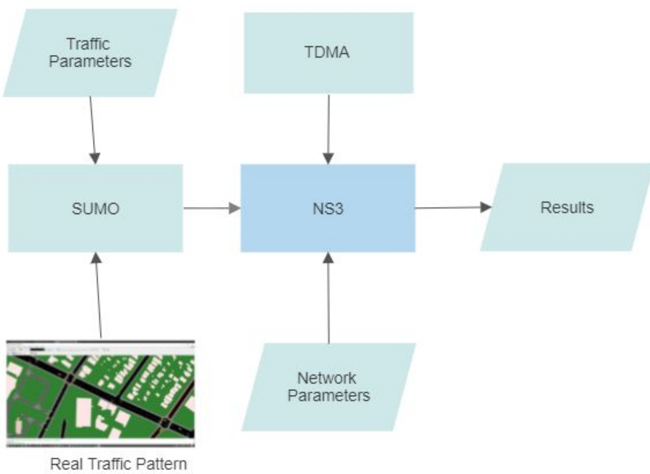

Fig. 5. Simulation Framework

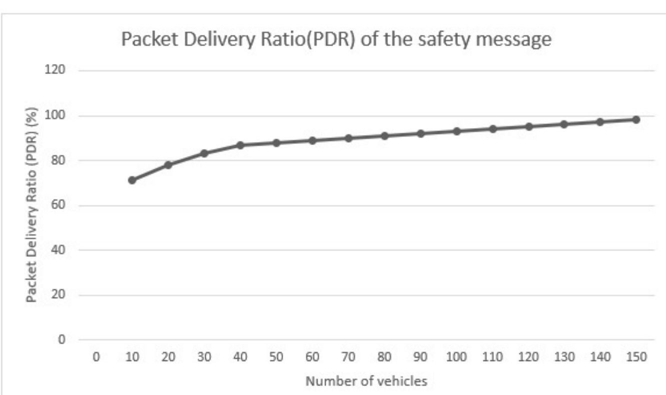

Fig. 6. Packet Delivery of messages vs Number of Vehicles

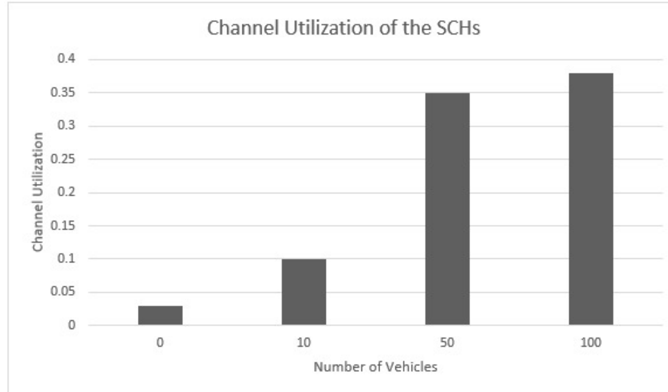

Fig. 7. Channel Utilization of the SCHs

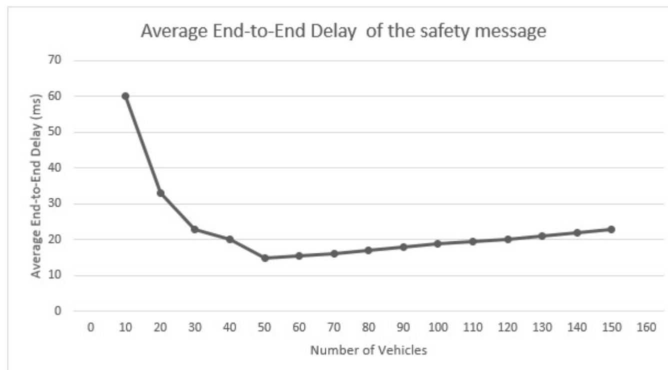

Fig. 8. End to End delay of messages

A. System Configuration

Table 1 shows the parameters used for the simulation. The frame size is taken to be 100. By allocating two mini-slots for each vehicle so as to transmit messages in consecutive slots in every synchronised intervals, packet delivery ratio is maximized. Every vehicle is at a random position and at a one-hop range of each other. Assuming a bounded delay of 100 ms for the messages to be transmitted signifies that if the packet is delivered after 100 ms, it is dropped.

TABLE I
Simulation Parameters

Parameter	Value
Cluster Range	300 m
Data rate of each channel	6 Mbps
Number of CCH	1
Number of SCHs	6
Safety/update Packet Size	200 bytes
Transmission Power	5.4 dBm
SINR Threshold	7 dB
Frame Size	100 ms
Simulation time	100 s
Vehicle Range	10 - 120
Speed Limit	29 m/sec

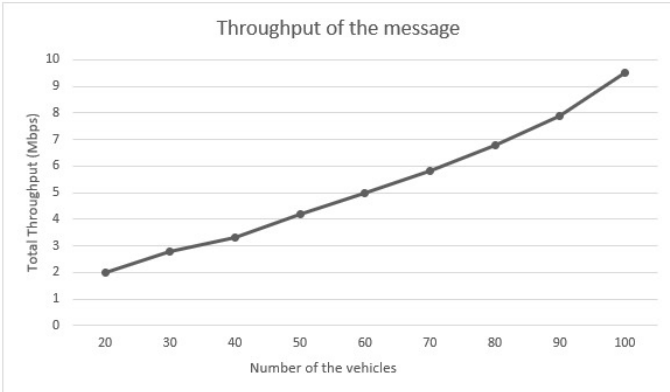

Fig. 9. Throughput vs Number of Vehicles

B. Packet Delivery Ratio

Packet delivery ratio can be defined as the percentage of packets of data that a vehicle receives successfully. It is given by the ratio of total number of packets received successfully to the total amount of packets sent. Every vehicle generates the messages randomly and transmits them at an interval rate of 10 packets/sec. With the assumption that every vehicle communicates in its cluster, there will be messages missed during transmissions of messages from vehicles which have its respective mini-slots in the CCH at the exact same slot. So, the proposed model has a good performance in this aspect as higher the vehicles, lower is the ratio of vehicles that switch between CCH to SCH which is also represented in figure 6.

C. End to End Delay

This metric can be defined as the time taken for successfully transmitted packets that carry the information to pass through different vehicles. Simulation results reveal that the end to end delay is higher when there are less vehicles and gradually reduces as the number of vehicles increase as shown in figure 8.

D. Throughput

It is generally defined as a measure of successful messages transmitted through a communication model. Usually measured in kbps, it is the efficiency of the protocol by which the destination receives the data packets. 50 broadcasting vehicles have been selected out of which 10 are RSU-to-Vehicles and Vehicle to Vehicle nodes belong to 20,30..90 and accordingly shows its performance as in figure 9.

E. Channel Utilisation

Channel utilisation is primarily measured in time where successful transmission of data packets is calculated in fraction of time. As the proposed communication model uses default SCHs and reallocates each unused slots, performance is good as shown in the figure 7.

VI. Conclusion and Future Scope

This paper has proposed a communication model that uses TDMA so as to avoid interference from other simultaneous transmissions. Signal to Noise Ratio is used to allow a simultaneous communication between nodes in a base station within a cluster. The model is simulated with SUMO and NS3 simulator and performance is shown. The model proposed provides: (i) Efficiency and fairness to achieve maximum data rate and rightness, (ii) channel utilization has been enhanced by reallocating the unused slots. Possible future work to improve the performance of the proposed model could be Priority Based Enhanced TDMA (PDMAC) which uses the concept of precise inter and intra clock synchronisation.

References

[1] Li, Shujing, Yanheng Liu, and Jian Wang. ”An efficient broadcast scheme for safety-related services in distributed TDMA-based VANETs.” IEEE Communications Letters 23, no. 8 (2019): 1432-1436.

[2] Cao, Shengbin, and Victor CS Lee. ”A novel adaptive TDMA-based MAC protocol for VANETs.” IEEE Communications Letters 22, no. 3 (2017): 614-617.

[3] Khairnar, Vaishali & Kotecha, Ketan. (2013). Performance of Vehicle-to-Vehicle Communication using IEEE 802.11p in Vehicular Ad-hoc Network Environment. International Journal of Network Security & Its Applications. 5. 10.5121/ijnsa.2013.5212.

[4] Abubakar Aminu Mu'azu1, Low Tang Jung1, Ibrahim A. Lawal1, Peer Azmat Shah1, "A QoS Approach for Cluster-Based Routing in VANETS Using TDMA Scheme," ICTC 2013.

[5] Tianjiao Zhang, Qi Zhu, "EVC-TDMA: An Enhanced TDMA Based Cooperative MAC Protocol for Vehicular Networks," Journal of Communications and Networks, Vol. 22, No. 4, August 2020.

[6] Leandro Aparecido Villas ” Data Dissemination in Vehicular Networks: Challenges, Solutions, and Future Perspectives” 978-1-4799-8784-9/15/©2015 IEEE DOI 10.1109/NTMS.2015.7266482 pp 1-5.

[7] Azizian, Meysam, Soumaya Cherkaoui, and Abdelhakim Senhaji Hafid. ”A distributed cluster based transmission scheduling in VANET.” In 2016 IEEE International Conference on Communications (ICC), pp. 1-6. IEEE, 2016.

[8] Hadded, Mohamed, Rachid Zagrouba, Anis Laouiti, Paul Muhlethaler, and Leila Azouz Saidane. ”An AdaptiveTDMA slot assignment strategy in vehicular ad hoc networks.” Journal of Machine to Machine Communications 1, no. 2 (2014): 175-194.

[9] The Network Simulator—ns-3. [Online]. Available: https://www.nsnam.org/