An Efficient Channel Access Scheme for Vehicular Ad-hoc Networks

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***Abstract*—Vehicular Ad-hoc Networks (VANETs) are getting more popularity due to the potential Intelligent Transport Systems (ITS) technology. It provides many efficient network services such as safety warnings (collision warning), entertainment (video and voice), maps based guidance, emergency information, etc. VANETs most commonly use Road Side Units (RSUs) and Vehicle-to-Vehicle (V2V) referred as Vehicle-to-Infrastructure (V2I) mode for data accessing. IEEE 802.11p standard which was originally designed for Wireless Local Area Networks (WLANs) is modified to address such type of communication. However, IEEE 802.11p uses Distributed Coordination Function (DCF) for communication between wireless nodes. Therefore, it does not perform well for high mobility networks such as VANETs. Moreover, in RSU mode timely provision of data/services under high density of vehicles is challenging. In this paper, we propose a RSU-based efficient channel access scheme for VANETs under high traffic and mobility. In the proposed scheme, the contention window is dynamically varied according to the times (deadlines) the vehicles are going to leave the RSU range. The vehicles with shorter time deadlines are served first and vice versa. Simulation are performed by using the Network Simulator (NS-3) v. 3.6. The simulation results show that the proposed scheme performs better in terms of throughput, backoff rate, RSU response time, and fairness.**

Keywords Contention window, IEEE 802.11p, Intelligent Transport System, RSU, VANET

I. INTRODUCTION

The significant improvements in the Intelligent Transportation System (ITS) have led the key advancements in the conventional IEEE 802.11p standard. In order to support the ITS services and applications (i.e., traffic management, traveler information, and public safety messages which are further divided into two classes; (i) periodic (beacon) safety messages and (ii) event driven messages) over Vehicular Ad-hoc Networks (VANETs), the Wireless Access in the Vehicular Environment (WAVE) standard has specified the required changes in the conventional IEEE 802.11p standard [1]–[3]. In dense and high traffic load scenarios the WAVE prioritizes the messages by which its delay increases significantly, however, its throughput decreases considerably. The Federal Communications Commission (FCC) has allocated 5.9 GHz and 5.8 GHz bands in the USA and South Korea, respectively for vehicular communication. Moreover, Dedicated Short Range Communications (DSRC) scheme is also proposed to allocate the spectrum for vehicular communications. This scheme, allocate spectrum between the vehicles and the roadside infrastructure or among the high speed vehicles within a range of upto 1 km.

In VANETs, vehicles can communicate with each other through roadside infrastructure known as Road

Side Unit (RSU) as well as directly. Direct communication between vehicles is called Vehicle-to-Vehicle (V2V) communication. However, the conventional IEEE 802.11p standard does not provide satisfactory operating environment for VANETs under high traffic load and high mobility. Whereas, high traffic density and high mobility causes more frequent network topology changes as well as fluctuations in traffic density. This happens because the IEEE 802.11p shares basic characteristics of Distributed Coordination Function (DCF) of IEEE 802.11 and IEEE 802.11e (EDCF) [3]–[9] such as carrier sensing procedures and service priority levels, respectively. If a vehicle has high speed its a likely chance that it will not be able to access the RSU for channel allocation while others can [10].

This paper presents an efficient channel allocation scheme which dynamically adapts the Contention Window (CW) for the vehicle according to the deadline. The deadline of each vehicle is calculated based on its speed. In the proposed scheme the CW for high speed vehicle and vehicle with emergency data is varied slowly which consequently gives quick access to the channel and vice versa. Simulation results present the comparative evaluation of the proposed scheme with conventional scheme and schemes proposed in [10] and [21]. The proposed scheme performs better in terms of throughput, backoff rate, and RSU response time and fairness.

The rest of the paper is organized as follows. In Section II, the related work is presented. Section III consists of motivations and main contribution, it also discusses the proposed RSU-based scheme for efficient channel access under high traffic load and mobility. Section IV presents the performance analysis. Finally, section V concludes the paper.

II. Related Work

We present a review of the work related to channel access for VANETs under high traffic density and high mobility conditions. The authors in [10] introduce clustering approach for periodic broadcasting of vehicle's information such as its one-hop neighbors and its average speed. Each cluster is maintained by a cluster head. The cluster head broadcasts messages to vehicles within its cluster. Due to high mobility of cluster heads routes/hops can be broken and established frequently resulting in overall low network performance. This scheme categorizes vehicles based on their speed deviation from average speed of neighboring vehicles. The vehicles adjust their CWs according to the three fixed contention window ranges and not based on the time they leave the range of the RSU.

The scheme proposed in [11] investigates the performance of IEEE 802.11p by proposing two approaches of adaptive backoff window sizes. One is centralized and other one is distributed. In the centralized scheme the base station knows the number of concurrent transmitting vehicles and uses this information to calculate the optimal window size. The number of transmitting vehicles information is broadcasted periodically by the base station. Once such a broadcast is received by a vehicle, it will calculate the optimal transmission probability. However, in distributed approach each vehicle only uses its local channel information to select the backoff time. Each vehicle increases its backoff window size when the number of vehicles increase and vice versa. The vehicle in solicitation-based IEEE 802.11p MAC protocol [12] solicits data frames in an opportunistic style by requesting transmissions of the frames from a WAVE Mode Basic Service Set (WBSS) provider by a WAVE-poll frame. This counters fast channel variation conditions due to speed variability of vehicles.

C. Suthaputchakun et al. in [13] deploy conventional IEEE 802.11e with EDCF mechanism for priority assignment in inter-vehicle communication. High priority messages are repetitively transmitted to increase the probability of transmission as compared to lower priority ones. This results in more collisions and congestion in the network. The scheme proposed in [14] does not use CW based access mechanism, rather it uses the concept of super-frame consisting of collision free and collision based phases. The vehicles are polled by the RSU according to their deadlines. Contention Free Period (CFP) is assigned 80% fixed length of the super-frame. However, N. Balon et al. in [15] have considered the number of frames received by each vehicle to estimate the reception rate of that vehicle. Each vehicle knows local state of the network by maintaining a table carrying entries for neighboring vehicle. The entries include a MAC address, the last sequence number, a weighted reception rate and a time stamp. CW is adapted according to the local reception rate of the vehicle. As the number of vehicles increase maintenance of tables gets time consuming and complex for highly varying and fast road traffic. Furthermore, the paper does not explain that how much CW is altered and how its threshold value is determined for comparison.

In [16], transmission power and CW for vehicles is dynamically adapted based on the vehicle density and instantaneous packet collision rate, respectively. In order to determine the estimated collision rate and adapt CW accordingly, the proposed scheme deploys the conventional IEEE 802.11 approach as well as uses the concept of local reception rate suggested by Balon and Guo in

[15]. The proposed scheme has almost the same issues as the scheme proposed in [15]. additionally, the algorithm compares the estimated collision rate with a threshold value to relate CW but does not discuss how this threshold value is calculated. The scheme proposed in [17] considers the priority of packets consisting of static and dynamic fields. The static priority field is defined according to the sender application and contents of the message. This factor consists of five priority levels adopted by car-to-car (C2C) Communication Consortium. Dynamic factor such as speed of the vehicle, message utility, and message validity are used to schedule messages. Message utility calculates the transmission zone covered by a vehicle i.e., smaller the zone, the higher is the priority to send the message. The message validity factor takes into account serving deadline of messages, the message whose deadline is earliest is served first.

In [18], authors calculate network traffic density to adjust the size of the CW. The proposed scheme estimates the channel conditions using packet transmission status. It maintains channel states in a vector to update the CW in order to improve throughput of a network. In [19], a performance analysis of IEEE 802.11p is presented under the exchange of small status messages known as beacons. Vehicles use these beacon messages for establishing cooperative awareness. The cooperative awareness is used by different applications increasing road safety and efficiency of ITS. The proposed scheme targets real-time vehicle control by enhancing the efficiency of IEEE 802.11p broadcasts. The size of CW is adaptive based on traffic density improving delay and reception probability. Authors present a self- adaptive CW based scheme in [20] to improve the efficiency of VANETs. The proposed scheme uses Persistence Factor (PF) for dynamic adjustment of CW size. Moreover, based on total local reception rate of past few seconds, a vehicle can adapt the CW dynamically. To ensure more deterministic dynamic range [1, CW(i)]. The proposed MAC protocol implements Sliding Contention Window (SCW) adaptive to changing network conditions, bound by the predefined range. The messages are prioritized according to their urgency for timely propagation. The integration of contention based MAC and IEEE 802.11e Enhance Distributed Channel Access (EDCA) increases the communication reliability.

Early Deadline First (EDF) concept is also introduced by I.EL Korbi et al. in [21], the authors develop a Markov chain-based analysis modeling the backoff process of the EDF policy. Moreover, the authors implement this scheme in MANETs to evaluate EDF policy over IEEE 802.11 in a multi-hop environment by considering two routing protocols; 1) proactive Destination Sequenced Distance Vector (DSDV) and 2) the reactive Ad-hoc On-Demand Distance Vector (AODV). However, the proposed scheme is developed for static environments. In [22], Duc et al. implement a MAC protocols increasing efficiency and reliability of VANETs. Both the control and service channel intervals are proposed to carry safety messages to ensure the security of broadcast messages. It is also proposed to use control channel for the transmission of service packets to improve the service throughput. Table I provides the comparison of the existing schemes in terms of EDF, adjustment of CW, throughput, and number of backoffs.

III. A RSU-Based Efficient Channel Access Scheme For VANETs Under High Traffic And Mobility

In the section, first we present our motivation and main contributions and then we discuss the RSU-based proposed scheme.

A. Motivation and Contributions

Our work is motivated by the observation that the existing schemes do not consider the fast changing topology of VANETs. Some of the schemes discussed in Section II are static in their nature; they have either deployed the conventional IEEE 802.11 or IEEE 802.11e EDCF mechanisms for channel access rendering the vehicles around RSU without timely provision of services or they are reactive in their operations such as the calculation of the parameters (tables, collision rate) to adapt the CW size is slow and complex process, which defeats the whole concept of real-time services for highly mobile vehicular traffic. Some of the mechanisms use conventional concepts of Mobile Ad-hoc Networks (MANETs) such as cluster head for cluster formation. Due to dynamic nature of vehicles in VANETs, routes/hops are frequently broken and established which results in overall degradation of network performance. Our proposed scheme follows the IEEE 802.11p standard which is particularly designed for WLANs and modify it to support VANETs. In the proposed scheme, priority is assigned to each vehicle based on its deadline. Furthermore, we determine the priority of each vehicle dynamically by changing its CW size according to its deadline. The CW for high speed vehicle having low Early Deadline First (EDF) are assigned small CW which adapts slowly as compared to the low speed vehicle having high EDF.

B. RSU-Based Proposed Scheme

The propose scheme deals with the following parameters:

TABLE I
COMPARISON OF EXISTING SCHEMES

Scheme	Applied on VANET	EDF	Adjustment of CW	Fast Topology	Throughput Calculated/Not calculated	Back-offs Calculated/Not calculated
W. Alasmary Scheme [10]	Yes	No	Adjust CW sizes according to the three fixed CW ranges based on their speed and not based on the time they leave the range of the RSU	Yes	Average compared to proposed scheme	Average compared to proposed scheme
Yi Wang [11]	Yes	No	No	No	Not calculated	Not calculated
N. Choi [12]	Yes	No	No	Yes	Not calculated	Not calculated
C. Suthaputchakun [13]	Yes	No	It defines min and max CW size	No	Not calculated	Not calculated
A. Bohm [14]	Yes	No	No	No	Not calculated	Not calculated
N. Balon [15]	Yes	No	Local reception rate of the nodes	No	Not calculated	Not calculated
D. Rawat [16]	Yes	No	It adapts the CW size considering the packet collision rate.	No	Not calculated	Not calculated
M.S Bouassida [17]	Yes	Yes	No	No	Not calculated	Not calculated
Balador, Ali [18]	Yes	No	Based on the network traffic density	No	Not calculated	Not calculated
Rene Reinders [19]	Yes	No	It adjusts the CW size based on traffic density.	No	Not calculated	Not calculated
Tanmay Vinay [20]	Yes	No	By sliding window with dynamic presistence factor (PF)	No	Not calculated	Not calculated
I.El Korbi Scheme [21]	No	Markov-Chain based model	No	No	Not calculated	Not calculated
Duc Ngoc [22]	Yes	No	No	No	Scheme is evaluated for improving throughput	Not calculated
Proposed Scheme	Yes	Priority Base Scheme	This scheme assigns priority to vehicles based on their deadline they leave the range of RSU. The priorities are determined on real-time basis by changing CW size according to the deadlines the vehicles are going to leave the RSU range.	Yes	Good as compared to W. Alasmary Scheme [21]	Good as compared to W. Alasmary Scheme [21]

1) speed of the vehicle,
2) direction of the vehicle with respect to the RSU,
3) emergency services,

The first two parameters are used to calculate the EDF value against each vehicle whereas the third parameter is used for tie breaking such as if multiple vehicles have the same value of EDF then the vehicle having emergency service will be served first. However, the vehicle with small or low value of EDF is considered as high priority vehicle and the vehicle with high value of EDF is considered as low priority vehicle. The traffic density of vehicles generally follows the curve as shown in the Fig. 1. As it is clearly seen from the figure that traffic density is high near road crossings. Therefore, the vehicle's prioritization is highly required at this point. The working of the proposed scheme is as follows:

1) the RSU selects the vehicle, which is moving towards it within its range,
2) time stamp of EDF is calculated for each vehicle, which is in the range of RSU. However, the EDF of a vehicle is calculated from its speed and geographic position as given below:

$$EDF = \frac{Distance\ from\ RSU}{Speed\ of\ the\ Vehicle} \quad (1)$$

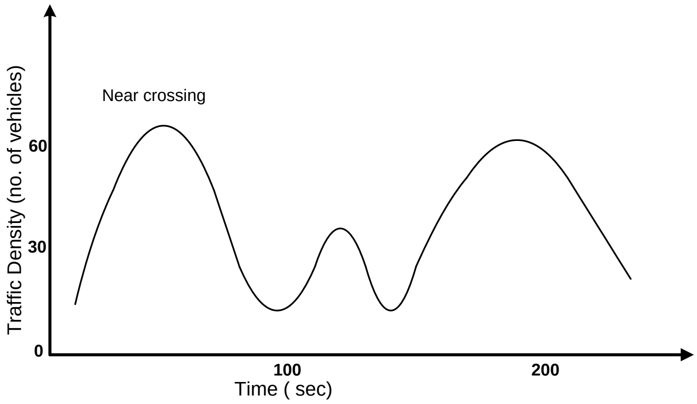


Fig. 1. Traffic pattern near road crossing.

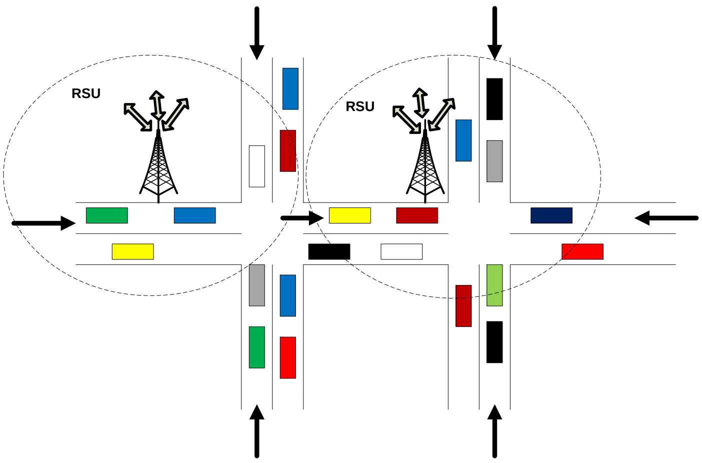


Fig. 2. Traffic Scheduling by RSU's.

TABLE II
PARAMETER USED FOR CHANNEL ACCESS IN PROPOSED SCHEME

Priority	EDF	CW change	CW min	CW max	AIFS
High	Low	Slow	3	7	SIFS+2*Slot-time
Medium	Medium	Medium	7	15	SIFS+2*Slot-time
Lowest	High	Fast	15	1023	SIFS+7*Slot-time

Each vehicle is assumed to know the service deadline of its request. This is reasonable because a GPS enabled vehicle can estimate the departure time based on its speed and geographic location. The high speed vehicle has high priority while low EDF. Therefore, it should be served first. Figure 2 shows traffic scheduling by RSUs.

3) after a vehicle establishes connectivity with the RSU, its geographic location and radio range of RSU is calculated through beacon messages. The vehicle can estimate its departure time, which is its service deadline with the help of its driving speed and position information. Moreover, the vehicles are grouped according to their EDF,
4) vehicles with lowest values of EDF shall be served first because they will cross the RSU range first. The CW for such vehicles should adapt slowly as compared to other vehicles with high values of EDF. The CWs for high EDF vehicles change quickly (doubled). The vehicles with low EDF values are considered as high priority and vice versa for high EDF value vehicles. In conventional IEEE 802.11 and EDCF standards [3]–[9], whenever, there is a collision the CW is always doubled to reduce number of collisions and it is set to minimum CW whenever there is a successful packet transmission irrespective of the conditions. Figure 3 shows the channel access mechanism of the proposed scheme. Moreover, the Table II demonstrates the selected parameters for channel access in the proposed scheme,
5) if multiple vehicles have the same value of EDF then the one with single hop emergency message or small size data will be served first,
6) if multiple vehicles with the same value of EDF are crossing the RSU then they may generates a broadcast storm which causes packet collisions. This situation is mitigated through Master-Slave scheme [10]. A cluster is created based on the transmission radius of the very first vehicle in the first lane when vehicles stop at a crossing point. The cluster will comprise of two types of vehicles one master and the rest are slaves. The master vehicle is the one having maximum signal strength that can covers the maximum transmission radius in the cluster and this aspect is decided by the RSU. In a cluster, only the master vehicle broadcasts messages to slave vehicles. If the slave vehicles in the cluster want to send specific messages , they send it to master vehicle for onwards transmission to other slave vehicles in a cluster or outside the cluster if necessary,
7) if the RSU is not able to serve the fast moving vehicles due to their high speeds then it transfers the request to the next RSU depending on the direction of the vehicle. This may avoid dropping of the requests and system can manage to handle the high speed vehicles requests in the same way as mobile network does,

Algorithm 1 and 2 calculate the EDF's of the vehicles moving towards the RSU and new contention window, respectively. Algorithm 1 calculates the EDF's of moving vehicles as follows:

1) for vehicle with least EDF (high priority), previous

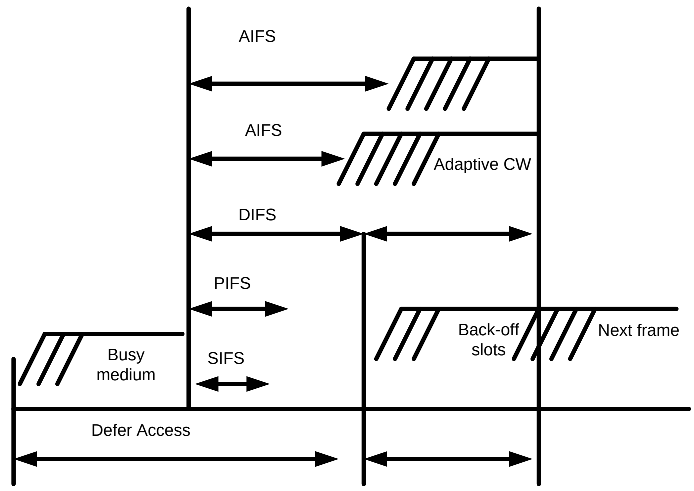


Fig. 3. Channel access mechanism of the proposed scheme.

Input: Vdc=Vehicle current distance, dp=Previous Distance, Rr= RSU Range
Output: Calculation of EDF
$initialization$;
begin
  while *Vehicle not crossing RSU* **do**
    $read\ current\ distance\ of\ Vehicle$
    if $Vdc < dp$ && $Vdc == Rr$ **then**
    $EDF = \frac{DistancefromRSU}{SpeedoftheVehicle}$;
    else
    $go\ back\ to\ the\ beginning\ of\ then\ section$;
  end
end

Algorithm 1: Calculation of EDF

Input: VEDF = Vehicle EDF
VLEDF = Vehicle Least EDF
VMEDF = Vehicle Medium EDF
PCW = Previous CW.
Output: Calculation of New Contention Window
$initialization$;
begin
  if $VEDF < PCW$ **then**
    $PCW \uparrow R(3-7)$
  end
  if $VEDF \geq VLEDF$ **then**
    $2 + R(7-15)$
  else
    $2 * R(7-15)$
  end
end

Algorithm 2: Calculation of New Contention Window

CW is increased linearly with the min limit of 3 and max limit of 7,

2) for vehicles with EDF greater than least EDF (medium priority), a factor of 2 is added to the previous CW with the min limit of 7 and max limit of 15,

3) for vehicle with EDF greater than medium priority (low priority), a factor of 2 is multiplied with the previous CW in min limit of 15 and max limit of 1023,

Algorithm 2 dynamically adapts the CW's of the vehicle which is present in the range of the RSU according to its EDF. It selects the vehicle as follows:

1) if the current distance of the vehicle is less than its previous distance and the vehicle is in the range of the RSU.

2) if current distance is greater than its previous distance and the vehicle is not within the range of the RSU,

IV. Performance Analysis

We present and discuss our simulation parameters and performance analysis of the proposed scheme with respect to conventional scheme and schemes proposed in [10] and [21]. Simulations are performed to evaluate the impact of mobility on IEEE 802.11p by using Network Simulator (NS-3) v. 3.6 [23]. Moreover, we use Simulation of Urban MObility (SUMO) as mobility simulator [24]. It is an open source microscopic, multi-modal traffic simulation package which includes net import and

TABLE III
Simulation Parameters

Parameters	Values
Network Area	500*500 m
Propogation Model	Two ray ground
Number of Vehicles	10,30,40,63
Speed	8 km/h to 100 km/h
Simulation Time	200 sec
Traffic Type	CBR
Radio Range	500 m
MAC Layer	IEEE 802.11p
Packet Size	512 bytes
Traffic Load	Packet sent every 1ms
Traffic Lights	1
No. of Lanes	3 in each direction
SIFS Time	25 micro second

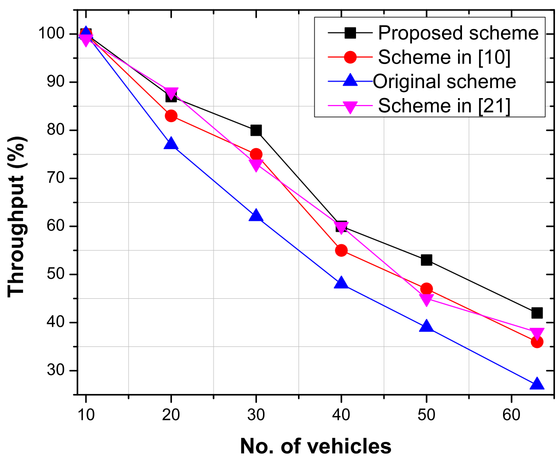


Fig. 4. Throughput of vehicles in the range of the RSU.

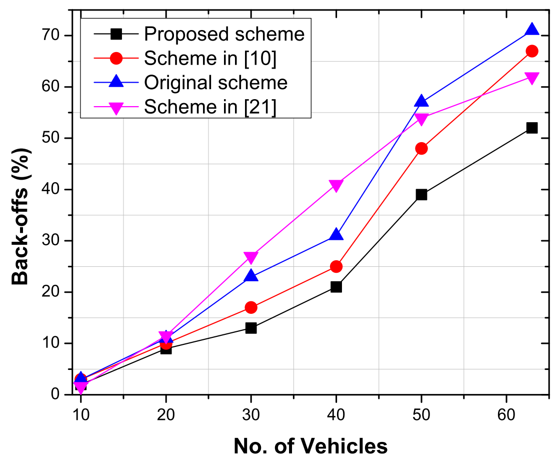


Fig. 5. Backoff rate.

demand modeling component. The simulation environment implements a 3-lane highway scenario. Each lane has a length of 3 km and a width of 10 m. The speed of vehicles variable from 8 km/h to 100 km/h. Whereas, each vehicle is using the IEEE 802.11p MAC protocol. Simulation time is set to 200 s for all the simulations results and the transmission range of each vehicle is set to 500 m. The packet length is set to be 512 bytes. The number of vehicles contending for the channel may varies from 10 to 63. The time slot parameter of IEEE 802.11p is set to be 10 sec, and SIFS time is 25 sec. Table III presents the simulation parameters.

Figure 4 shows the throughput analysis of the proposed scheme, the conventional scheme and the schemes proposed in [10] and [21]. It is clear from the figure that the throughput decreases as the number of vehicles increases. This is due to the reason that when the RSU serves more vehicles the contention for channel increases, leading to more packet losses which consequently decreases the throughput. Hence, the proposed scheme performs better than the other schemes even with more number of vehicles.

Figure 5 presents the simulations analysis in terms of backoff rate. Number of backoffs increase as the number of vehicles increase. However, the proposed schemes in [10] and [21] do not adapt CW according to the priority of vehicles. Therefore, they cause more backoffs compared to the proposed scheme.

Figure 6 presents performance comparison of RSU response times for 10, 30, 40, and 63 vehicles. It is clear from the figure that the response time of RSU in the proposed scheme is less compared to the conventional scheme as well as the schemes proposed in [10] and [21] under the high traffic load scenarios. This is because the proposed scheme assigns priority to the high speed vehicles (less EDF) by assigning smallest CW and slowly varies it, whereas, the schemes proposed in [10] and [21] assign priority to the vehicles based on the deviation from the average speed of the neighbors. It means that vehicles with extremely high deviation (low and high speeds) from the average speed are assigned high priority compared to the vehicles with average speed which in this case varies between 50 km/h to 60 km/h. This is the reason of a sharp rise of response time at these average values. In our propose scheme, we assign priorities to the vehicles on the basis of deviation d which is calculated as follows:

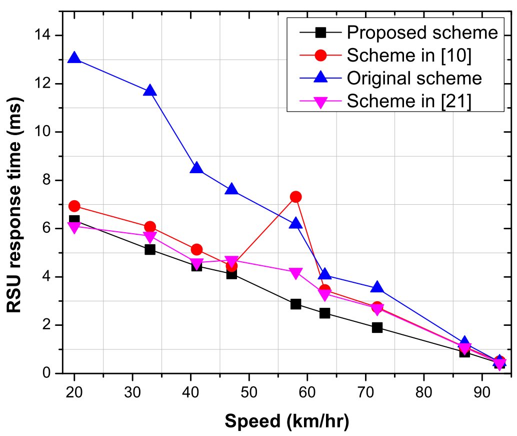
$$d = [V_i - V] \tag{2}$$

Where V is the average speed and V_i is actual speed of a vehicle.

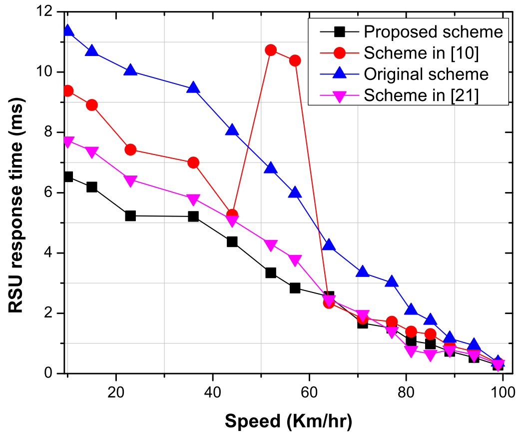
Figure 7 shows the values of Jains fairness index plotted against the number of vehicles. Jains fairness index is calculated as follows:

$$f(x_1, x_2, x_3, ..., x_n) = \frac{(\sum_{i=1}^{n} x_i)^2}{n \sum_{i=1}^{n} (x_i)^2}. \tag{3}$$

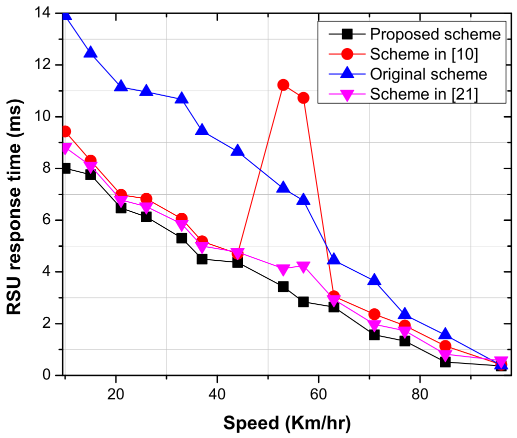
Where n represents the number of vehicles, x_i denotes the throughput for the i^{th} connection. The result range from $1/n$(worst case) to 1 (best case) and it is maximum when all the users receive the same allocation. Simulation show poor Jain fairness index at low number of vehicles. This is because some vehicles have less connectivity than the others. Whereas, the frequent fragmentation of



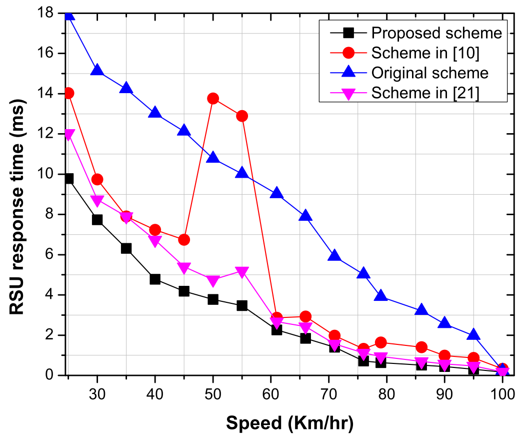
(a) RSU response time for 10 vehicles.



(b) RSU response time for 30 vehicles.



(c) RSU response time for 40 vehicles.



(d) RSU response time for 63 vehicles.

Fig. 6. RSU response time for 10, 30, 40, and 63 vehicles.

the network is one of major reason for less connectivity of vehicles. Fairness index increase with the number of vehicles increase or with the more high traffic density.

V. Conclusion

In this paper we propose a RSU-based efficient channel access scheme for VANETs under high traffic and mobility conditions. It dynamically adapts the contention window of each vehicle based on it deadline of departure from the range of RSU. The contention window for higher priority packets is varied slowly and vice versa for lower priority ones. Simulations are performed to evaluate the mobility impact on the standard IEEE 802.11p. Our simulation results demonstrate that the proposed scheme performs better than the conventional scheme and schemes proposed in [10] and [21] in terms of throughput, backoff rate, RSU response time, and fairness.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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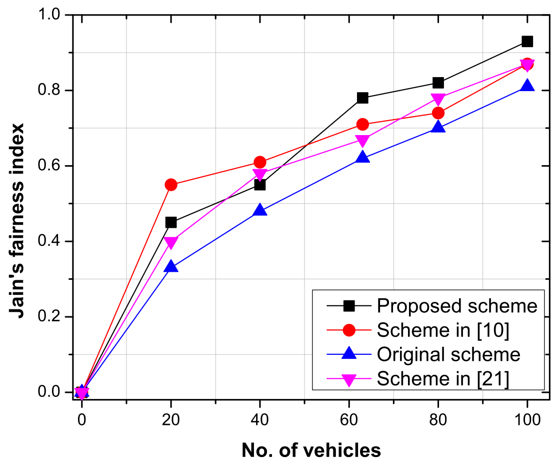

Fig. 7. Jain's fairness index.

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