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RESEARCH ARTICLE

Optimizing Vehicular Safety Message Communications by Adopting Transmission Probability With CW Size

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ABSTRACT Vehicular ad hoc networks (VANETs) will have noteworthy breakthroughs with the upcoming 5G and 6G technologies. In VANETs, the performance changes with traffic, contention window (CW) size, and vehicle velocity. Since the velocity and number of vehicles are not controllable, CW size will be optimized to maximize performance. In this paper, performance is optimized for highly important safety messages (sm) in VANETs by optimizing CW size with respect to number of vehicles and vehicle velocity. If any of these parameters (velocity and/or number of vehicles) changes, CW size will be dynamically adjusted to keep performance at optimum level. The comparison between IEEE 802.11 and IEEE 802.11p for sm in VANETs is presented where performance is maximized for both IEEE 802.11 and IEEE 802.11p. Markov chain based analytical model is developed and optimum expressions are derived. SUMO is used to build the microscopic mobility model. Monte Carlo simulation results are provided which verify analytical study and demonstrate that the performance is maximized regardless of parameters variation.

INDEX TERMS CW size, delay, optimization, safety messages, throughput, VANETs.

I. INTRODUCTION

Recently, vehicular ad hoc networks (VANETs) have gained importance for intelligent transport systems (ITS). A main component of ITS is the VANET that supports communication between vehicles to vehicles (V2V), and vehicles to infrastructure (V2I). Fig. 1 demonstrates a VANET scenario. The MAC protocol is one of the most salient elements of any ad hoc network since it is directly responsible for efficient and reliable data transfer. For VANETs, MAC and physical (PHY) layer specifications are outlined in the IEEE 802.11 standard [1], which was incorporated in the IEEE 802.11p standard [2]. Distributed coordination function (DCF) is a basic MAC layer access mechanism that uses a backoff technique based on carrier sense multiple access with collision avoidance (CSMA/CA). Moreover, request to send (RTS) and clear to send (CTS) technique is utilized to solve the issue of hidden vehicle.

Performance can change with contention window (CW) size [3], [4], [5], variation of traffic [6], [7], [8] and vehicle velocity [9], [10], [11]. In practice, the number of vehicles and vehicle velocity cannot be controlled, CW size can be adjusted to optimize performance. Recently, performance improvement of safety messages (sm) in VANETs has been studied in [12], [13], and [14]. In [12], the effect of the CW size is examined and dynamic contention window (DCW) size is proposed. However, freezing of backoff and velocity are not considered and only IEEE 802.11p standard is considered in [12]. To increase the performance in VANETs, a backoff algorithm is proposed based on suggested threshold of CW size in [13]. In [13], low or high traffic is decided by the threshold of CW size that is not realistic and optimum CW size should be considered. A single-hop broadcasting analytical model is studied in [14] to obtain the closed-form expressions of throughput under saturated

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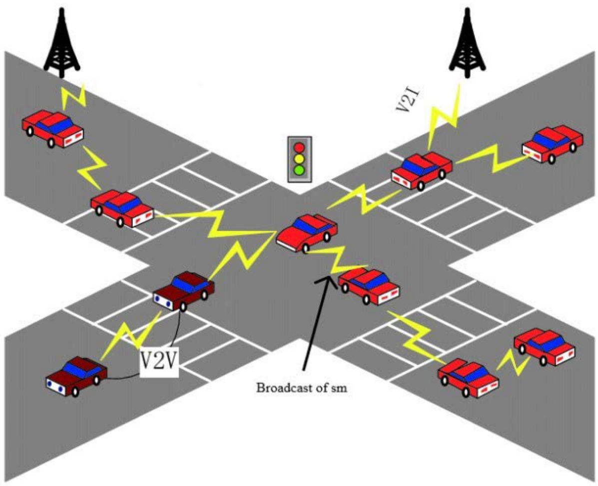


FIGURE 1. VANET scenario.

condition. However, the authors do not consider the velocity in [14]. In practice, the performance may significantly decrease with the variation of parameters. Therefore, the main goal of the paper is to achieve maximum performance always by dynamically adjusting CW size with the varying parameters. In this paper, performance in terms of throughput, packet dropping rate (PDR), and delay are considered. Throughput will be maximized, and PDR and delay will be minimized to optimize the performance. In our previous study, we studied IEEE 802.11p [8] and IEEE 802.11 [9], [10] separately. We evaluated the performance. In this study, we optimized the performance based on our previous studies and presented a comparison between them.

A summary of the paper's novelty is given below:

- For sm, probability of transmission is optimized by using optimum CW size to maximize the performance in VANETs. In VANET, optimum transmission probability should be adopted by each vehicle, which can be attained by adjusting the CW size, to optimize performance.
- Thus, optimum CW size is determined for the number of vehicles and vehicle velocity.
- An analytical study is presented which uses Markov chain model. Following Bianchi model [15] for VANETs, optimum expressions of transmission probability and CW size are obtained.
- Simulation results are provided that verify analytical study.
- Simulation of urban mobility (SUMO) [16] is utilized to construct the microscopic mobility model. First, a microscopic mobility model is created in SUMO, and then output of SUMO is utilized as an input to MATLAB.
- With existing proposals of adapting the contention window in IEEE 802.11 ad hoc networks, a quantitative comparison is provided. The performance is improved as shown in simulation results.

The remaining sections of the paper are ordered as follows: Section 2 features related works. Section 3 draws an overview of IEEE 802.11p and IEEE 802.11 backoff technique. Optimization mechanism is sketched in Section 4. Analytical study and simulation results are presented in Section 5. The paper wraps up in Section 6.

II. RELATED WORKS

The performance analysis of IEEE 802.11 DCF is scrutinized in [15]. Bianchi's work [15] has been extended in most recent publications. In [15], only throughput analysis is presented but delay analysis is not. Performance analysis of the IEEE 802.11 for VANET is studied in [9] and [10]. The effect of IEEE 802.11p for VANET is studied in [8], [17], [18], and [19]. It is obvious from these studies that the performance of both standards is influenced by CW size, variation of traffic, and vehicle velocity. The performance for sm is crucial [20], [21] in VANETs which has been investigated in [12], [13], and [14]. However, in [12], backoff freezing and velocity are not taken into account, and just the IEEE 802.11p standard is used. Low or high traffic is determined in [13] by a CW size criterion that is unrealistic, and the optimal CW size should be addressed. The velocity is not taken into account in [14]. In [22], to obtain better performance the length of the control channel interval (CCI) is optimized and CCI is split in relation to frame type. To propagate sm and to increase the throughput of service channels in VANETs, [23] proposes dynamic control channel interval. However, variation of traffic, and vehicle velocity are not considered in [23]. Therefore, a study for performance optimization based on practical variation of traffic, and vehicle velocity is needed. Due to VANETs' changing topology, the time division multiple access (TDMA) MAC protocols may waste time slots. Wastage happens if there are not enough nodes in the network to fill all of the time slots in a frame. Although the channel is idle during unreserved time slots, the sender waits for the following frame to retransmit after a failed transmission, which results in high latency and low throughput in VeMAC [24]. Moreover, these methods might not be efficient in making use of the available radio resources. Furthermore, TDMA requires timing synchronization.

III. OVERVIEW OF IEEE 802.11p AND IEEE 802.11 BACKOFF TECHNIQUE

The finite state machine (FSM) of IEEE 802.11p and IEEE 802.11 backoff mechanism is provided in Fig. 2. In IEEE 802.11p, when a node has a sm, the sm is broadcast in the VANET. Acknowledgement (ACK) is not used for broadcast packets, thus unsuccessful transmissions due to collisions with other packets cannot be distinguished. Therefore, their contention window (CW) does not change. In IEEE 802.11, transmission is acknowledged by ACK. After each failed transmission, CW doubles until maximum value $CW_{\max} = 2^{m_r} CW_{\min}$, where m_r denotes the maximum retransmission limit. Algorithms of backoff mechanism for IEEE 802.11p and IEEE 802.11 are presented in Algorithm 1 and Algorithm 2, respectively.

In algorithms, CH denotes channel and CH_i denotes idle channel. T_{wait} and T_{DIFS} are duration of waiting and DCF

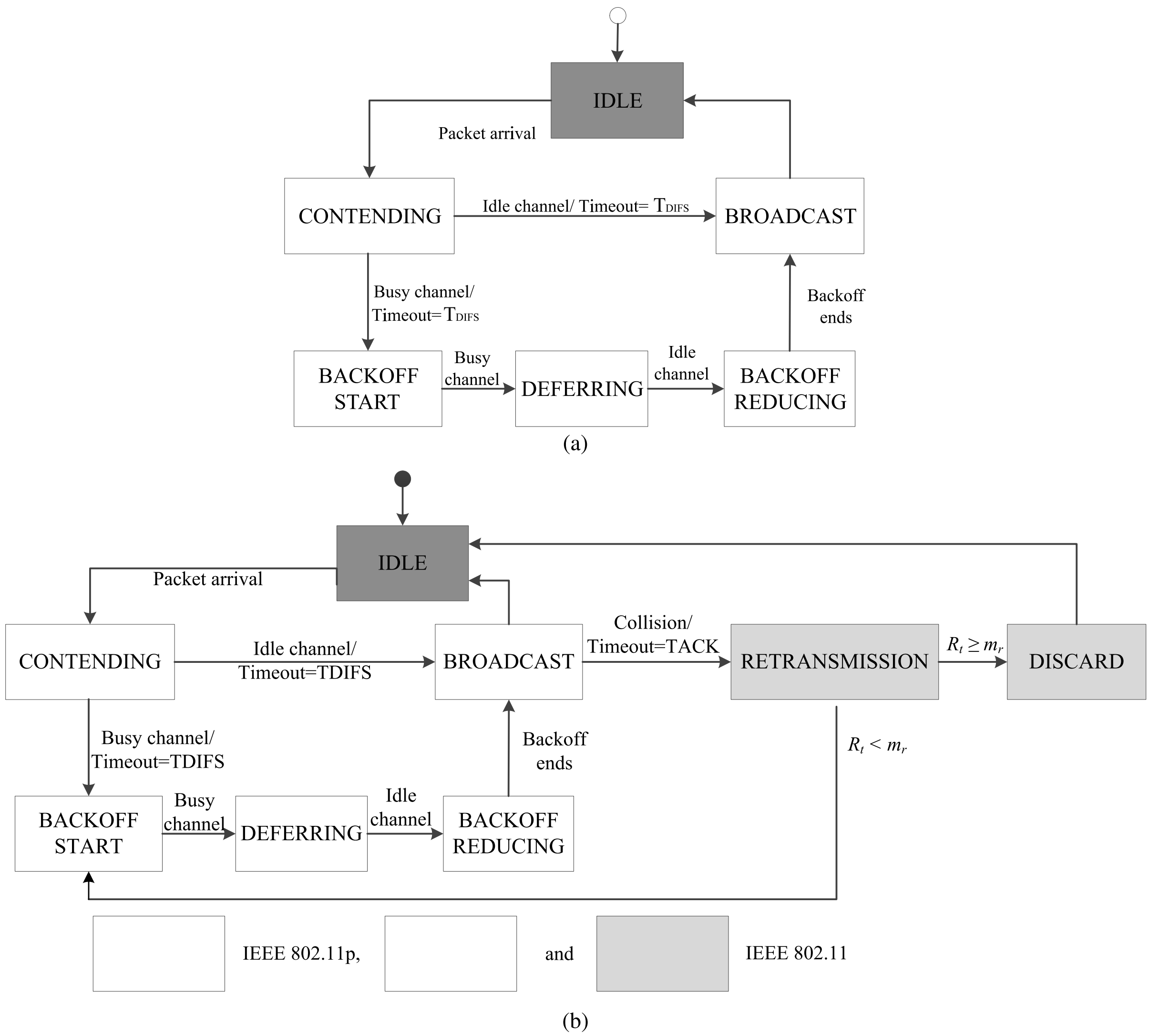


FIGURE 2. FSM of IEEE 802.11p and IEEE 802.11 backoff mechanism. (a) IEEE 802.11p. (b) IEEE 802.11.

Algorithm 1 Algorithm of IEEE 802.11p Backoff

if $CH = CH_i$ **then**
  $T_{wait} = T_{DIFS}$ still $CH = CH_i$
  Broadcast
end if
if $T_{wait} > T_{DIFS}$ **then**
  wait for $CH_i = T_{DIFS}$
  $\text{backoff}_i = CW_{min}$
  if $CH = CH_i$ in each slot **then**
    $\text{backoff}_i = \text{backoff}_i - 1$
  else
    $\text{backoff}_i = \text{backoff}_i$
  end if
end if
if $\text{backoff}_i = 0$ **then**
  Broadcast
end if

inter frame space, respectively. U_{ACK} is the set of ACK and R_t denotes number of retransmissions. Backoff timer is initially assigned at random, and denoted as $CW_{\min}$ and reduced by 1 when the channel is listened idle in a slot time, and put on hold when the channel becomes busy, and decremented when the channel is listened idle once more for higher than T_{DIFS}. The packet will be sent when backoff timer expires. In Algorithm 1, the broadcast remains unacknowledged. Therefore, failed transmission in IEEE 802.11p cannot be distinguished and there is no change in CW size. On the other hand, sender waits for ACK for the broadcast in IEEE 802.11. In IEEE 802.11, if the ACK is not received, then the transmission is marked as a failed transmission. After failed transmission due to collision, R_t will be increased by 1. After each failed transmission, CW doubles until maximum value $CW_{\max}$. If $R_t \geq m_r$ then the packet will be discarded.

Algorithm 2 Algorithm of IEEE 802.11 Backoff

1: **if** $CH = CH_i$ **then**
2: $T_{wait} = T_{DIFS}$ still $CH = CH_i$
3: Broadcast
4: **end if**
5: **if** $T_{wait} > T_{DIFS}$ **then**
6: wait for $CH_i = T_{DIFS}$
7: backoff$_i$ = CW_{min}
8: **if** $CH = CH_i$ in each slot **then**
9: backoff$_i$ = backoff$_i$ - 1
10: **else**
11: backoff$_i$ = backoff$_i$
12: **end if**
13: **end if**
14: **if** backoff$_i$ = 0 **then**
15: Broadcast, $T_{wait} = T_{SIFS}$
16: **if** ACK $\in$ U$_{ACK}$ **then** Transmission is completed
17: **end if**
18: **else if** $R_t < m_r$ **then**
19: $R_t = R_t + 1$
20: backoff$_i$ = 2 CW_{min}
21: **if** backoff$_i$ = 0 **then**
22: Broadcast, $T_{wait} = T_{SIFS}$
23: **if** ACK $\in$ U$_{ACK}$ **then** Transmission is completed
24: **end if**
25: **else** go to step 17
26: **end if**
27: **else if** $R_t \geq m_r$ **then**
28: Discard
29: **end if**

IV. OPTIMIZATION MECHANISM

A VANET is considered where N vehicular nodes are arbitrarily distributed on a multilane road. Let S be the normalized system throughput, i.e. data transmitted over mean length of a slot time which can be given as [8], [9], and [10]

$$S = \frac{P_{suc}P_{busy}L}{T_e} = \frac{P_{suc}P_{busy}L}{(1-P_{busy})T_{slot} + P_{busy}P_{suc}T_{suc} + P_{busy}(1-P_{suc})T_{col}}, \quad (1)$$

where L is the length of data. T_{slot}, T_{col} and T_{suc} and T_e are duration of a slot, collided packet, successful delivery, and expected time in each Markov state, respectively. P_{suc} and P_{busy} denote successful transmission probability and channel busy probability, respectively, which can be given as [8], [9], and [10]

$$P_{suc} = \frac{NP_t(1-P_t)^{N-1}}{P_{busy}}, \quad (2)$$

$$P_{busy} = 1-(1-P_t)^N, \quad (3)$$

where P_t is the packet transmission probability in a slot time which can be given for IEEE 802.11p as well as IEEE 802.11, respectively as [8], [9], and [10]

$$P_{t-IEEE802.11p} = b_0 = \frac{2}{CW+1}, \quad (4)$$

$$P_{t-IEEE802.11} = \sum_{i=0}^{m_r} b_{i,0} = \frac{b_{0,0}}{1-P_{col}} = \frac{2(1-2P_{col})}{(1-2P_{col})(CW+1)+P_{col}CW(1-(2P_{col})^{m_r})}, \quad (5)$$

where P_{col} is collision probability which can be given as [8], [9], and [10]

$$P_{col} = 1-(1-P_t)^{N-1}. \quad (6)$$

The P_{col}, which is currently unknown, affects $P_{t-IEEE802.11}$ in general. It is sufficient to know that at least one of the N-1 remaining stations must transmit within a time slot for a sent packet to experience a collision in order to determine the value of P_{col}. According to the basic independence presumption stated above, each transmission "sees" the system in the same condition, i.e., in steady state [15]. However, the exponential backoff stage is not necessary to take into account when $m_r = 0$. Then P_t is independent of P_{col} and eq. (5) is much simpler as $P_t(0) = \frac{2}{CW+1}$. When $P_{col} = 1/2$, P_t can be given as $P_t = \frac{2}{1+CW+m_rCW/2}$.

T_{col} and T_{suc} and T_e can be given as [8], [9], and [10]

$$T_{col-IEEE802.11p} = \frac{L_h+L}{R_d} + T_{DIFS} + T_{delay}, \quad (7)$$

$$T_{col-IEEE802.11} = T_{DIFS} + T_{SIFS} + T_{RTS} + T_{delay}, \quad (8)$$

$$T_{suc-IEEE802.11p} = \frac{L_h+L}{R_d} + T_{DIFS} + T_{delay}, \quad (9)$$

$$T_{suc-IEEE802.11} = T_{DIFS} + 3T_{SIFS} + (N-1)T_{RTS} + (N-1)T_{CTS} + \frac{(N-1)L}{R_d} + (N-1)T_{ACK} + T_{delay}, \quad (10)$$

$$T_e = (1-P_{busy})T_{slot} + P_{busy}P_{suc}T_{suc} + P_{busy}(1-P_{suc})T_{col}. \quad (11)$$

Let X represent the mean of the number of vehicles on the road section. By using Little's law, X can be given as [25]

$$X = \lambda T_e, \quad (12)$$

where λ is the average arrival rate of vehicles which can be given as

$$\lambda = n_L k_{density} v, \quad (13)$$

where n_L is the lane's number on the road, v represents mean vehicle's velocity and $k_{density}$ is traffic density which is the vehicle's number per unit distance per lane. $k_{density}$ varies linearly with v as

$$k_{density} = k_{jam}\left(1-\frac{v}{v_f}\right), \quad (14)$$

where k_{jam} is the severity of traffic jam at which traffic flow halts and v_f is the velocity in free-flow.

Utilizing eq. (8) to (9) in (7), the X can be rewritten as

$$X = n_L k_{jam}\left(1-\frac{v}{v_f}\right) vT_e. \tag{15}$$

The mean number of vehicles in transmission range (R_t), can be calculated as [14]

$$E[N] = XR_t. \tag{16}$$

Now, eq. (1) can be reorganized as

$$S = \frac{L}{T_{suc} - T_{col} + \frac{P_{busy}(T_{col}-T_{slot})+T_{slot}}{P_{suc}P_{busy}}}. \tag{17}$$

Since L, T_{suc}, T_{col}, and T_{slot} are constants, to maximize S the following expression should be optimized:

$$\frac{P_{suc}P_{busy}}{P_{busy} + \frac{T_{slot}}{(T_{col}-T_{slot})}} = \frac{NP_t(1-P_t)^{N-1}}{\left(1-(1-P_t)^N\right)+k}, \tag{18}$$

where $k = \frac{T_{slot}}{T_{col}-T_{slot}}$. In (13), k is constant and N is not controllable. Therefore, P_t has to be optimized to have optimum throughput. After obtaining the derivative of the right side in expression (13) with respect to P_t and setting 0, results in:

$$kNP_t - k + (1-P_t)^N + NP_t - 1 = 0. \tag{19}$$

The series expansion can be written as Pt $\ll$ 1, [15] and [26]

$$(1-P_t)^N \approx 1 - NP_t + \frac{N(N-1){P_t}^2}{2}, \tag{20}$$

Using (15), (14) can be given as

$$kNP_t - k + \frac{N(N-1){P_t}^2}{2} = 0. \tag{21}$$

Thus, optimum P_t can be obtained from (16) as

$$P_t = \frac{\sqrt{kN(kN+2N-2)} - kN}{XR_t(N-1)}, \tag{22}$$

where $N > 1$. When we take the second derivative of (13) with respect to P_t, the value of P_t is negative, because right part of the expression is always >1 that is

$$P_t = 1 - \sqrt[N-1]{k+1}, \tag{23}$$

which indicates that the P_t is the maximum. Algorithm 3 is the optimization mechanism.

By using (5) and (17), the optimum CW can be obtained for IEEE 802.11 as

$$CW_{opt-IEEE802.11} \approx \left\lceil \left(\frac{2n_L k_{jam}\left(1-\frac{v}{v_f}\right) vT_e R_t(N-1)}{\sqrt{kN(kN+2N-2)} - kN} - 1\right) / (1+m_r) \right\rceil, \tag{24}$$

where $\lceil . \rceil$ denotes ceil operation. By using (4) and (17), the optimum CW can be obtained for IEEE 802.11p as:

Algorithm 3 Algorithm for P_t Optimization

1: Start
2: Set N
3: Compute S
4: $\frac{dS}{dP_t} = 0$
5: Find the root of ${P_t}'$
6: **if** root of ${P_t}' > 0$ then **then**
7: $\quad \frac{dS^2}{dP_t^2} = 0$
8: **end if**
9: Find the root of ${P_t}''$
10: **if** root of ${P_t}'' > 0$ then **then**
11: $\quad \frac{dS^3}{dP_t^3} = 0$
12: **else if**
13: $\quad$ **then**${P_t}'$ is the optimum
14: **end if**
15: **end**

$$CW_{opt-IEEE802.11p} \approx \left\lceil \frac{2n_L k_{jam}\left(1-\frac{v}{v_f}\right) vT_e R_t(N-1)}{\sqrt{kN(kN+2N-2)} - kN} - 1 \right\rceil. \tag{25}$$

By using the optimum value of CW which will adopt the optimum value of P_t, the optimum throughput S is obtained as

$$S = \frac{L}{T_{suc} - T_{col} + \frac{(1-(1-P_{t\_opt})^N)(T_{col}-T_{slot})+T_{slot}}{NP_{t\_opt}(1-P_{t\_opt})^{N-1}}}. \tag{26}$$

A packet is discarded after maximum retransmission limit (m_r). So, PDR can be given as

$$PDR = (1-P_s)^{m_r}. \tag{27}$$

The optimal PDR can be obtained by adopting optimum P_s, which can be attained from optimal P_s by using optimum CW size.

Now, average packet delay $E[D]$ can be written as [8], [9], and [10]

$$E[D_{IEEE802.11p}] = T_e\left(N - \frac{P_{drop}}{1-P_{drop}} \times \frac{CW+1}{2}\right), \tag{28}$$

$$E[D_{IEEE802.11}] = T_e\left(N - \frac{P_{drop}}{1-P_{drop}} \times \frac{2}{1+CW+m_r CW/2}\right), \tag{29}$$

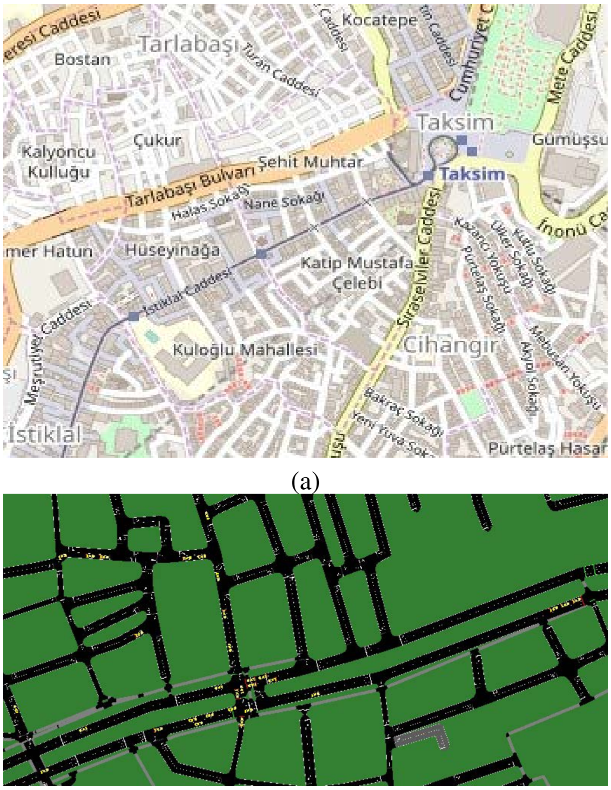
where P_{drop} is the probability that a packet will be finally dropped. The optimum $E[D]$ can be obtained by adopting optimal Te that can be accomplished from optimum P_t by using optimum CW size.

V. ANALYTICAL AND SIMULATION RESULTS

The simulation results are carried out using a 2.30 GHz Intel Core i5-4200U CPU and 8 GB RAM. The simulation is accomplished with MATLAB and SUMO. First, a model of microscopic mobility is created in SUMO, after that, the

TABLE 1. Parameter values utilized in simulations.

Symbol	Value for IEEE 802.11	Value for 802.11p
$T_{slot}, T_{SIFS}, T_{DIFS}, T_{delay}$ (μs)	20, 10, 50, 1	20, 30, 50, 1
L, L_{th} (bytes)	512, 50	512, 50
RTS, CTS, ACK (bytes)	26, 20, 14	N/A
R_{dt} (Mbps)	11	11
N, m_r, n_L	0-150, 0-9, 2	0-150, 0-9, 2
v, v_f (km/h)	0-120, 160	0-120, 160
k_{jam} (vehicle/m), $R_t(m)$	120, 500	120, 500



(a)

(b)

FIGURE 3. (a) Traffic area map, (b) Traffic simulation in SUMO 1.2.0.

output of SUMO is utilized as input to MATLAB, and simulation results are obtained by 1000 Monte Carlo iterations. We compared the simulated results to actual measurements in SUMO to confirm the accuracy of our approach. The settings for vehicle speed and vehicle number were selected to suit the SUMO's technical data that we utilized for validation. Fig. 3a shows the map of the area considered and 3b shows traffic simulation generated in SUMO. We considered the area of Taksim square in Istanbul, Turkey. The broadcast nature of safety messages is considered. For each figure, Table 1 lists the parameter values that were utilized in the simulation. N is 100 for IEEE 802.11 and 802.11p in Fig. 5. The CW size is 64 for IEEE 802.11 as well as 802.11p in Fig. 4 and Fig. 5. It takes 17.98 ms in order to find the optimum CW size.

Throughput versus number of vehicles is demonstrated in Fig. 4. The throughput of IEEE 802.11p standard is better than IEEE 802.11 for sm because RTS/CTS handshake of IEEE 802.11 is inactive in broadcast mode as CTS is needed for RTS in RTS/CTS handshake. Thus, when sm is broadcast to all vehicles, all vehicles require to transmit CTS. Hence, sending simultaneous CTS will result in more collisions [27]. Moreover, when a rebroadcast is needed, then there will be redundant rebroadcasts. These broadcasts could be in intense contention with one another. Throughput increases with increase in the number of vehicles until a certain level, after that the throughput begins to fall. Since there would not be collision until certain traffic, but after that when more packets will be sent in the same time slot there would be more collision. It is noticeable that the throughput is always maximized because CW size is dynamically adjusted for the number of vehicles.

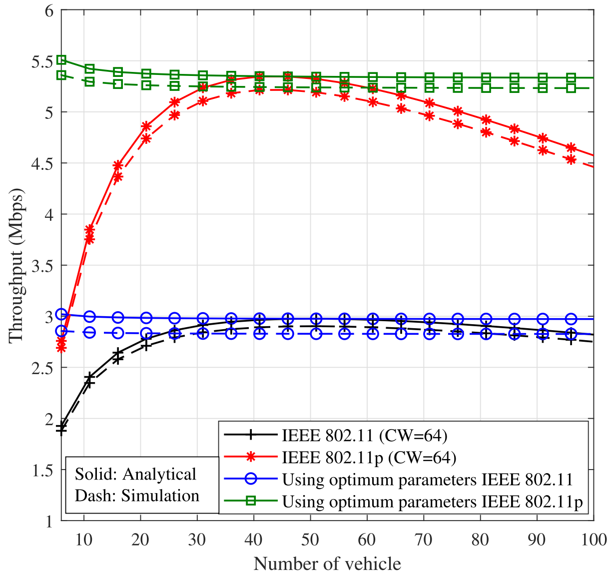


FIGURE 4. Throughput versus number of vehicles.

Fig. 5 presents throughput against vehicle velocity. Throughput is decreasing when vehicle velocity increases because vehicle mobility changes network topology promptly which results in unstable communications and triggers collision plus packet loss. CW size is dynamically adjusted with the variation of vehicle velocity, which achieves maximum throughput. When speed is very low (up to 30 km/h) the improvement is low but the improvement is increasing after 30 km/h. Maximum vehicle velocity is the real time value obtained from SUMO and utilized in all simulations except Figure 5. In Figure 5, we showed the effect of the velocity and used v and v_f.

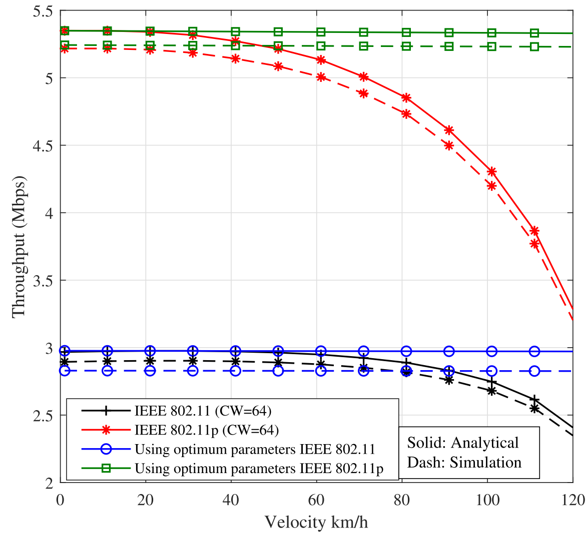


FIGURE 5. Throughput versus vehicle velocity.

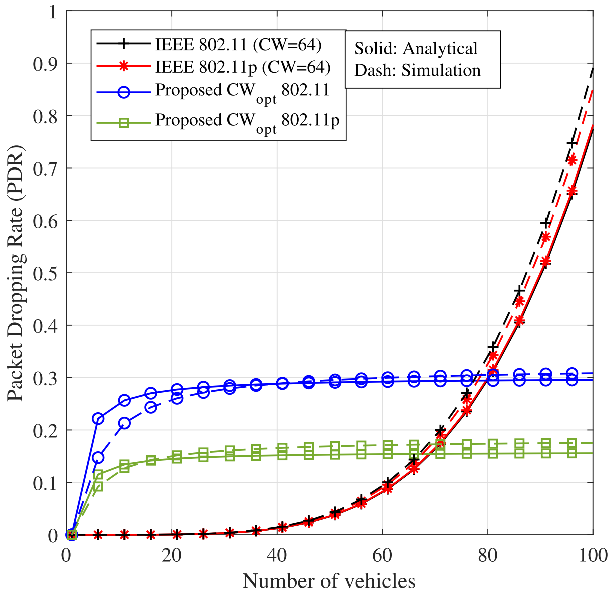


FIGURE 6. Packet dropping rate versus number of vehicles.

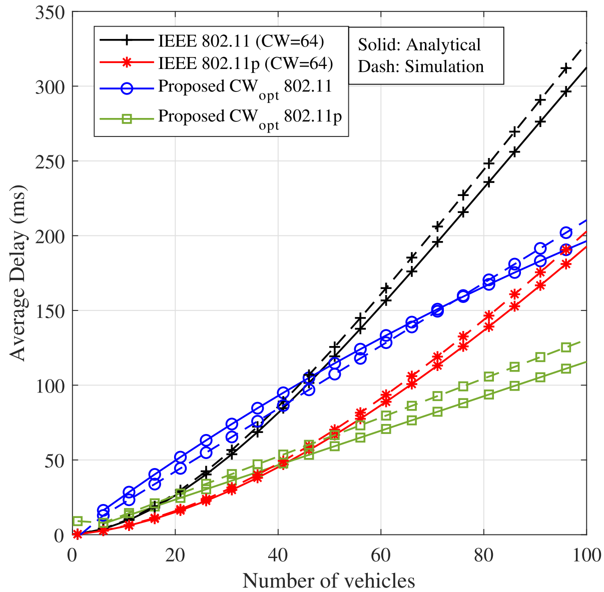


FIGURE 7. Average delay versus number of vehicles.

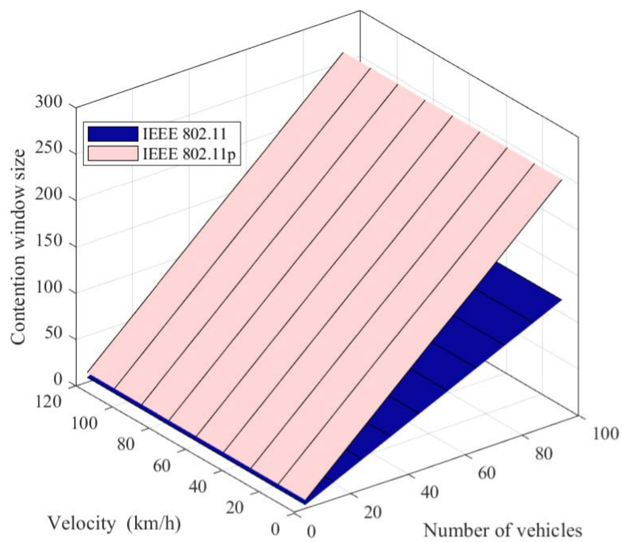


FIGURE 8. Optimum parameters variations for IEEE 802.11 and IEEE 802.11p in 3D.

Fig. 6 shows packet dropping rate (PDR) against number of vehicles. PDR is rapidly increasing in tandem with the vehicle's number on the road. It is also noticeable from the figure that the PDR of optimization mechanism is higher when traffic is low, but when number of vehicles is increasing, PDR of the optimization mechanism is less than IEEE 802.11 and IEEE 802.11p. Specially in high traffic scenario, PDR is very high in both 802.11 and IEEE 802.11p. On other hand, proposed optimization mechanism can make communication reliable and stable by decreasing PDR in high traffic scenario.

Fig. 7 presents average delay versus number of vehicles. Since IEEE 802.11 uses RTS/CTS handshake, for broadcasting sm, RTS will be sent to all nodes and CTS and ACK will be received from all nodes. Therefore, extra time is required for sending (N-1) RTS, and receiving (N-1) CTS and ACK. Moreover, when a rebroadcast is needed, there could be intense contention with one another. Therefore, the delay is higher for IEEE 802.11 as compared to IEEE 802.11p. Average packet delay rises dramatically as the number of vehicles increases. Since collision probability increases with the number of vehicles, PDR and delay increase. It is clear from the graphic that the delay of the optimization mechanism is slightly higher when vehicle's number is low, but it is noticeably low when traffic is high. However, none of the techniques fulfils the severe delay criterion of 100 ms for sm when the number of vehicles is high [26], [27], [28], [29], [30], [31], [32].

Optimum parameters variations for IEEE 802.11 and IEEE 802.11p in 3D is presented in Fig. 8. *CW* size is taken based on number of vehicles and vehicle velocity. *CW* size varies according to velocity and the number of vehicles as seen in the size of the *CW* changes according on the velocity and number of cars, as seen in the diagram. From the figure, it is noticeable that IEEE 802.11p requires higher *CW* size than IEEE 802.11 to have optimum performance.

Adapting the contention window in IEEE 802.11 ad hoc networks is studied in [33], [34], [35], [36], [37], and [38]. The maximum throughput attained versus the number of nodes in prior research is around 0.75 Mbps, 1.2 Mbps, and 1.6 Mbps in [33], [34], and [35], respectively, under the same network scenario. Alternatively, in our proposed technique, the maximum throughput is around 3 Mbps. The average delay for 50 nodes in the same network scenario is 250 ms, 480 ms, 500 ms, and 600 ms in [13], [36], [37], and [38]. On the other hand, in our proposed mechanism, it takes 110 ms.The optimization mechanism is proposed based on different parameters to adapt the contention window such as no of stations [33], active stations [34], the distance between stations [35], consecutive idle slot [36], backoff freezing process [37], and channel congestion status [38]. On the other hand, in our proposed mechanism, the probability of transmission is optimized by using optimum CW size with respect to the number of vehicles and vehicle velocity.

VI. CONCLUSION AND FUTURE WORKS

In this paper, the performance of highly important safety messages in VANETs is maximized by optimizing transmission probability with *CW* size. To obtain optimized performance, optimum transmission probability should be adopted by each vehicle, which can be attained by dynamically adjusting *CW* size with the number of vehicles and vehicle velocity. Thus, optimum *CW* size is derived based on vehicle's number and vehicle velocity. An analytical study using Markov chain model is presented. Optimum expressions for probability of transmission, and *CW* size are obtained. The comparison between IEEE 802.11 and IEEE 802.11p for sm in VANETs is provided. Performance is optimized for both IEEE 802.11 and IEEE 80211p. The model of microscopic mobility is created in SUMO. Performance of optimization mechanism is examined and analytical analysis is verified through Monte-Carlo simulations. Simulation results depict that the performance of proposed scheme is better than both IEEE 802.11 and IEEE 802.11p, and stated goal is achieved. Future studies may take into account the non-saturated condition with channel fading and capture effect. Moreover, the broadcast storm also influences performance which also includes future research works.

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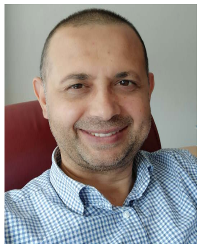

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