Analytical Models and Performance Evaluation of Vehicular-to-Infrastructure Networks With Optimal Retransmission Number

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Research

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Analytical models and performance evaluation of vehicular-to-Infrastructure networks with optimal retransmission number

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Abstract

Vehicle-to-infrastructure and vehicle-to-vehicle communications has been introduced to provide high rate Internet connectivity to vehicles to meet the ubiquitous coverage and increasing high-data rate internet and multimedia demands by utilizing the 802.11 access points (APs). In order to evaluate the performance of vehicular networks over WLAN, in this paper, we investigate the transmission and network performance of vehicles that pass through AP by considering contention nature of vehicles over 802.11 WLANs. Firstly, we derived an analytical traffic model to obtain the number of vehicles under transmission range of an AP. Then, incorporating vehicle traffic model with Markov chain model and for arrival packets, M/G/1/K queuing system, we developed a model evaluating the performance of DCF mechanism with an optimal retransmission number. We also derived the probability of mean arrival rate $\lambda$ to AP. A distinctive aspect of our proposed model is that it incorporates both vehicular traffic model and backoff procedure with M/G/1/K queuing model to investigate the impact of various traffic load conditions and system parameters on the vehicular network system. Based on our model, we show that the delay and throughput performance of the system reduces with the increasing vehicle velocity due to optimal retransmission number $m$, which is adaptively adjusted in the network with vehicle mobility.

Keywords: Vehicular-to-Infrastructure networks, IEEE 802.11 medium Access control (MAC), vehicular traffic networks
1 Introduction

Demand for on the move access to internet, for mobile users in the vehicles has stimulated the research study on vehicular networks [1]. Vehicular communications can mainly classified into vehicular-to-network (V2N), vehicular to vehicular (V2V), vehicular-to-infrastructure (V2I) and vehicle-to-pedestrian (V2P) communications. Several research has been made to study [2-4] V2I and V2V communications and in particular, vehicular ad-hoc networks (VANETs) have recently started to promose as a promising solution for vehicular communications.

5.85-5.925 GHz band frequency is allocated to short range communication band as a emerging radio standart for promoting the communication in safe and efficient highway or high-speed freeways. Basically, wireless access devices used in vehicles can be utilized permanently scan for signals from available access points (AP) and report the real-time traffic conditions signal and data captured along the way (e.g. data dissemination latency, roadway congestion levels) and also to enable drivers and on board-passengers with permanently enhanced safety and entertainment.

Internet access requests and real-time traffic to roadside unit (RSU), are conveyed by users traveling by car usually in the range of multiple WiFi access points (APs). At roadsides and intersections WiFi networks can be deployed along the highways with their low-cost high-capacity low coverage nature. In WLANs, contention-based medium access control (MAC) has been widely adopted such as IEEE 802.11 Distributed Coordination Function (DCF). The IEEE 802.11 DCF networks, defines a maximum retransmission number for each arrival packet, i.e, the retry limit [5]. At each retransmission, the packet is transmitted and then after the value of retransmission number reaches the maximum limit, vehicles may retransmit a packet and then an optimal retransmission limit will be on effect of DCF mechanism and the time pasted in retransmission will
be shortened, thereby delay and throughput performance of packets transmitted in vehicular networks would be improved.

Some recent efforts have been studied on the performance of vehicular networks [6-9]. However, these works often ignore the network performance with the optimal retransmission limit through constructing on corporate analytical Markov model and queuing network. Most of these studies focus on numerical evaluation of network throughput and delay performance for an initial given network sets, i.e, retransmission number is usually assumed to be fixed number in which larger number is enlarging the delay of successfully transmitted packets.

In this paper, we provide an analytical model to evaluate the network throughput, access delay and impact of optimal retransmission number, $M$ on performance of vehicular-to-infrastructure networks over WLAN. By incorporating vehicle traffic model with Markov chain model, and for arrival packets, $M/G/1/K$ queue system, we developed to model evaluating the performance of DCF mechanism with an optimal retransmission number. Based on traffic model, we derive the number of vehicles in the network, i.e, network size, the mean arrival rate $\lambda$ to AP. Then, relationship between network size and transmission and collision probability of a vehicle is derived. Based on developed model, for arrival packets patterns, with an iterative algorithm we derive the optimal retransmission number associated with Markov model's derived parameters.

The rest of paper is organized as follows: In section II, we discuss the related work. In section III, we describe the our proposed analytical traffic model, Markov chain model and queuing analysis in detail and in Section IV we provide numerical studies to evaluate the performance of our analytical models. We conclude the paper in Section V.

2 Related works
Studying the performance of the vehicle-to-infrastructure communications for the 802.11 MAC has drawn considerable attention of many researchers in the literature. Based only on slowly varying large-scale fading channel information, in [10], an optimal power allocation has been investigated for vehicular-to-X(everything) communications to maximize the sum throughput of V2N links while guaranteeing V2X links' reliability and latency. In highway environment, a number of performance models of the IEEE 802.11p, enhanced distributed channel access (EDCA) has been proposed [11-14].

Taking into account all major factors that could affect the access performance of the IEEE 802.11p ADCA mechanism including the saturation condition, standard parameters, backoff counter freezing and internal collision, a 2-D Markov and 1-D discrete-time Markov chain has been developed to model backoff procedure of an access category (AC) queue and establish a relationship between transmission probability and collision probability of the AC queue. Moreover, considering with hidden terminal problem and message strict priorities, a two-directional vehicular ad-hoc network (VANET) model has also been proposed in [13,14]. By direct (or one-hop) broadcast approach on the control channel (CCH), analysis of the 802.11p safety-critical broadcast in VANET environment has been studied in [12]. To show impact of performance anomaly at the intersections in WiFi-based vehicular networks in [15], a signal-to-noise (SNR) based admission control scheme that excludes vehicles with bad channel qualities an analytical model has been developed.

Performance anomaly problem, in [17], also has been studied to improve overall system throughput by proposing a simple and intuitive opportunistic medium access that grants wireless access only to vehicles with good SNR.

By taking into account the randomness of the vehicle traffic and statistical variation of the disrupted communication channel, in [16] an analytical framework has been in order to obtain the
maximum distance between adjacent RSU’s that stocastically limits the worst case packet delivery
delay to a certain maximum value. For drive-thru internet, that heavily affected by the contention
overhead of the uplink, upload performance (from vehicles to the AP) has been studied in [9-10]
by considering the contention nature of the uplink and realistic vehicle traffic model.

Using three different measurement settings, in [18] network characteristics has been investigated
and reference parameters for equipment with UDP-based test tools has been obtained and
possibilities and limitations for the use of scattered WLAN by devices has been discussed.

To explore QoS performance in term of throughput and delay, in [19], a comprehensive analytical
model that takes into account both QoS features of EDCA and the vehicle mobility (velocity and
moving directions), has been developed. To optimally adjust parameters of EDCA towards the
controllable QoS provision to vehicles. For impact of mobility on the resultant throughput, and
accurate analytical model that incorporates the high-node mobility with the modeling of DCF was
proposed in [20]. For vehicle-to-roadside communications, mobility pattern is very different.
Different nodes do not have similar channel access the channel, which is called fairness problem
As a solution to this problem, in [21] the authors a modified 802.11 DCF channel access scheme
was proposed by changing the probability of transmission through changing the minimum
contention window size.

These proposed models, however, assumes that maximum retransmission number is constant or
infinite, which would detoriate the delay and throughput performance of overall system due to non-
oneoptimal or consequetive and unlimited retransmissions, which can not capture the impact of
retransmission number in the network performance. Impact of retransmissions in the vehicular
transmission performance, a number of models for IEEE 802.11 DCF networks have been proposed
in [22,25,26]. However, they don't construct the proposed analytical models extensively to perform
with MAC queuing model taking the packet arrival rates, average packet size, average network size considerations caused by the queue in the vehicular environment.

The study effect of the time wasted in retransmissions, in [23] with a finite retry-limit, an analytical framework has been proposed on the performance optimization of CSMA networks and it is shown that with a finite retry limit, the network performance could be highly sensitive to the value of retransmission number $M$. In [24], the authors obtained explicit expressions for the mean of the total packet delivery ratio in an unsaturated network formed by moving on highway to investigate the performance of a modified DCF that uses a fixed number of sequential retransmissions to improve the reliability of a packet delivery.

3 Methodology

In this section, we will model the real-time transmission processes over 802.11 Wireless LAN, quantitatively analyze the performance of the system, and derive the parameters that can guide the engineering of the system for the optimal performance.

In deriving the optimal throughput, we consider that the network works in the saturation condition and each vehicle always has packets to transmit, i.e., the probability of an empty queue is zero. Under a high traffic load, a packet queue may be full and additional arrival packets will be blocked from entering the queue thus the WLAN system.

3.1 Traffic model

In particular, one consider the following types of descriptions.

- Microscopic description: All vehicles are individually identified.
- Kinetic description: probability distribution.
- Macroscopic description: locally averaged quantities.
In the literature, traffic flow is analyzed by experimental data[27,28] which refers to flow and averaged velocity of vehicles as function of the vehicular density.

Relationship between flow-density results in fundamental diagrams. The mean speed-density curve results in velocity diagram.

The traffic flow rate $\lambda_{tag}$, which refers to the arrival rate of vehicles to the road segment, to AP can be express as

$$\lambda_{tag} = kv$$  \hspace{1cm} (1)

where $k$ denotes the vehicle density that corresponds to the number of vehicles per unit distance in each lane along the road segments.

Based on Greenshield's model [29], speed-flow-density diagrams, can be constructed. Figure 1 shows the relationsheeps between traffic flow($\lambda$), density ($k$), and speed ($v$). A number of important points exist on this diagrams. Traffic flow is zero, when there are no vehicle on the road segment and when the vehicle density take its highest value and vehicle speed limit, $V_f$. If speed increases density starts to decrease, when speed is zero, density takes its highest value because all vehicles on the road stop and traffic flow $\lambda$, is also stop.

Traffic flows in vehicular networks can be generally divided into two major types: Uninterrupted and interrupted [30].

First type uninterrupted is defined as all the flows individually regulated by vehicle-to-vehicle interactions and interactions between vehicles and the roadway. The second type, interrupted flow is regulated by an external means, such as a traffic signal.

In this paper, we chose to consider only uninterrupted flows. In particular, we also chose to consider microscopic model representation, in which all vehicles seperately described and position and velocity of each vehicle determine the state of the system.
The vehicle density $k$ linearly changes with the average velocity $v$ as

$$k = k_{jam} \left(1 - \frac{v}{v_f}\right)$$

(2)

where vehicle jam density at which traffic flow rate is $k_{jam}$ and free-flow speed is $V_f$, which corresponds to highest speed when the vehicle is driving on the road segment (usually taken as the road's vehicle speed limit).

The mean sojourn time of each vehicle in the coverage of AP is given by

$$T = \frac{L}{v}$$

(3)

where $L$ is the length of the AP’s coverage range.

The network capacity of the system ($C$), which is maximum number of vehicles that can be accommodated by the AP's coverage range is given by

$$C = k_{jam} \cdot L$$

(4)

The mean vehicle population in the road segment $N$, is

$$N = \lambda_{tag} \cdot T$$

(5)

Based on M/D/C/C queuing model, $P_N$, the steady-state probability that there are $N$ vehicles simultaneously under the coverage of the AP is given by [31]

$$P_N = \frac{(\lambda_{tag})^N / N!}{\sum_{i=0}^{C} (\lambda_{tag} T)^i / i!}$$

(6)

As mentioned before, we consider the uninterrupted flows, M/D/C/C queuing model is for uninterrupted vehicular flow, (not interrupted stop-and-go traffic flows), i.e., there aren't any external means).
3.2 Markov chain model

In DCF mechanism, each packet contends for the channel transmission randomly. According to traffic model, $N$ number of vehicles contend for the transmission to the channel. The channel status is monitored during the idle period and if a channel is sensed idle period and if a channel is sensed idle with a duration of distributed interframe space (DIFS) time, when a packet arrives at queue in a vehicle, a packet can be transmitted. If the channel is sensed busy, a vehicle node will backoff and will continue to sense the channel again idle and not immediately compete for the channel access again and the backoff counter will be start up with the initial value set to random period within the backoff window selected from $[0, W]$ where $W=W_{\text{min}}$. The backoff window size, $CW_{\text{min}}$ initially set, will be doubled with each additional collision. Then, if channel sensed idle in a slot time, the backoff counter will be decremented by 1. When backoff counter becomes zero, the packet will be transmitted. We denote the number of backoff stages as $j$, and the size of contention window at the $j$th backoff stage is $CW_{j}=2j*CW_{\text{min}}$, $0<j<m$, $m$ being the maximum number of retransmissions limit that will be reached, which is allowed with our derivation. If the $m$ limit is reached, the value of $CW$ will be reset to $CW_{\text{min}}$.

At time $t$, if we have $j$ backoff stages and backoff counter is set as $i$, part of states are denoted by $s(t) = j$ and $b(t) = i$. The value of $i$ is uniformly distributed in the range $[0,CW-1]$.

We model the random process $s(t)$, $b(t)$ as a discrete-time two dimensional Markov chain denoted by

$$ bj, i = P\{s(t) = j, b(t) = i\}, $$

which represent one-step the steady-state probability. State transition diagram for each vehicle is shown Fig 1. At the maximum number of backoff stages, $m$, the maximum contention window size $CW_{\text{max}}=CW_{\text{min}}=2m*CW_{\text{min}}$. 
If the channel is sensed busy and collision happened, if there is at least one of other vehicles also initiates the transmission at the same time, then probability of a packet being collided is denoted as $p_c$.

Whenever there is a collision, the Markov chain moves from collision stage $j-1$, and waits for a random backoff time to avoid collisions and the counter will reduce by one after each time slot if the medium is sensed idle.

To find the one-step transition probabilities of the Markov chain $b_{j,i}$ form the transition diagram, we will first establish the balance equations. We have

$$b_{j-1,0}p_c = p_{j,0}$$  \hspace{1cm} (7)

$$p_{j,0} = p_c^j b_{0,0}$$ \hspace{1cm} (8)

$$b_{i-1,0}p_c = (1 - p_c) b_{i,0} \rightarrow b_i = \frac{p_c^i}{1 - p_c} b_{0,0}$$  \hspace{1cm} (9)

For each $i$ in $[0, CW_{j-1}]$, the steady-state probability $b_{j,i}$ is given by

$$b_{j,i} = \frac{CW_{j-i}}{CW_j} \begin{cases} (1 - p_c)(b_{i,0} + b_{0,0}), & j = 0 \\ p_c(b_{i-1,0} + (1 - p_c)b_{i+1,0}) & 0 < j < m \\ p_c(b_{m,0} + b_{m-1,0}) & j = m \end{cases}$$  \hspace{1cm} (10)
The probability of transmission is successful given in a slot time defined as $P_s$. If at least one of vehicle transmits during a slot time, when the channel is busy and probability of transmission is denoted as $P_{tran}$.

The collision probability $p_c$, the success probability $P_s$, and the transmission probability $P_{tran}$ are given respectively as follows

$$b_{0,0} = \frac{2(1-2p_c)(1-p_c)}{(1-2p_c)(CW_{\text{min}}+1) + (p_cCW_{\text{min}}(1-(2p_c)^m))}$$  \hspace{1cm} (11)
The parameter $\tau$ is the probability that a vehicle would transmit a packet in a given time slot. At the steady-state, the collision probability $p_c$ depends on $\tau$, while $\tau$ also depends on the backoff duration thus $p_c$, $\tau$ can be calculated from the Markov chain as the total probability that a counter reaches 0 from any of the m transmission attempts and is represented as follows:

$$\tau = \sum_{j=0}^{m} b_{j,0}$$  

Equations 12 and 15 are solved iteratively to determine the unknown parameters $\tau$ and $p_c$ until a converging condition is met. After the $m$-th backoff stage, a packet is discarded in the Markov chain model.

3.3 M/G/1/K Queuing analysis

We apply the M/G/1/K queuing model, where $K$ represents the maximum capacity of the queue at a vehicle. Packets arriving after $K$ packets are already in the queue are dropped. Call arrivals of real time applications are assumed to follow the Poisson process and the arrival rate to a vehicle $n$ is given by $\lambda$ (packets/s) and the arrival rate matrix for all N vehicles is $\lambda = \text{diag}(\lambda_1, \lambda_2, \ldots, \lambda_N)$.

The steady-state probability of the queue with $k$ packets is $\pi(k)$ where $k=0,1,2,\ldots,K$. Each packet is transmitted using the full channel capacity $C$.

Let $E[L]$ denote the average packet size (in bytes) in the MAC layer protocol. Average MAC service time is defined as the time from a packet reaches the head of M/G/1/K queue at the vehicle.
to the time it successfully departs from the queue, and is calculated as the time to transmit the average payload size within the retransmission limit m. The average service time $E[T_s]$ is calculated as:

$$E[T_s] = \frac{L}{C}$$  \hspace{1cm} (16)

The mean offered traffic load or traffic intensity from each vehicle $N$ is

$$\rho = \lambda E[T_s]$$  \hspace{1cm} (17)

Average data payload size $L$ is given by

$$L = E[L]\tau(1-p_c)$$  \hspace{1cm} (18)

The average duration it takes to transmit a packet in one transmission stage, $E[T_{slot}]$, is given as

$$E[T_{slot}] = (1-P_{tran})\delta + P_{tran}P_{suc}T_{suc} + P_{tran}(1-P_{suc})T_{col}$$  \hspace{1cm} (19)

where $\delta$ is the duration of the empty slot time, $T_{suc}$ and $T_{c}$ represent the duration for successful transmission and duration of collision, respectively. The probability that the channel is empty for slot time is given by $P_t=(1-P_{tran})$.

The duration due to successful transmission is calculated as:

$$T_{suc} = T_s + T_{SIFS} + T_{ACK} + T_{DIFS} + \delta$$  \hspace{1cm} (20)

The time cost in the collision $T_{c}$ is calculated as:

$$T_{col} = T_{header} + T_{DIFS} + T_d$$  \hspace{1cm} (21)

where $T_{header}$ and $T_d$ represent respectively the transmission time of the packet header and propagation delay.
In M/G/1/K queuing model, data packets are produced according to Poisson arrival process. Packets arriving at finite-size queue buffer accommodating $K$ packets follow a Poisson distribution. In one slot time, packet arrival probability is determined by

$$P\{\lambda(t) = j\} = P_\lambda = \sum_{k=1}^{K} \frac{(\lambda E[T_{slot}])^k}{k!} e^{-\lambda E[T_{slot}]}$$

(22)

We present the proposed searching scheme in Algorithm 1.

**Algorithm 1.** Proposed m optimal retransmission number searching algorithm

(Determining algorithm of optimal retransmission number)

---

Input: Set of $k_{jam}$, $V_f$, $L$, $T_{delay\_upper}$, $P_{c\_init}$, $M$, $\lambda_{init}$

Output: $T_{delay}$, $S$, $P_{c}$, $P_{tran}$, $N$, $C$, $\lambda_{tag}$, $m$

---

**begin**

1: $V(n)$=$(V_{(n)1}, V_{(n)2}, \ldots V_{(n)L}$

2: **for** $n \leq L$

3: \hspace{1em} $k(n)=k_{jam}(1-V(n)/V_f)$

4: \hspace{1em} $\lambda_{tag}(n)=k(n) V(n)$

5: \hspace{1em} **if** $k(n)>k_{jam}$ **then**

6: \hspace{1em} **stop**

7: \hspace{1em} $T(n)=L/V(n)$

8: \hspace{1em} $N(n)=\lambda_{tag}(n).T$

9: \hspace{1em} **for** $i \leq N(n)$ **do**

10: \hspace{2em} $\pi(i)=(1-\rho) \rho^i(1-\rho^{i+1})$

11: \hspace{2em} $pc(i)=1-(1-\tau)^{N-i}$
12: \textbf{for} \ j \leq M \ \textbf{do} \\
13: \ \ \ \text{compute } p_{\text{cur}}(j); \ \text{compute } T_{\text{delay}} \\
14: \ \ \ \text{compute } T_{\text{delaycur}}; \ \text{compute } S_{\text{cur}} \\
15: \ \ \ \textbf{end} \\
16: \ \ \ \text{compute } T_{\text{delay}} \\
17: \ \ \ \textbf{if} \ T_{\text{delay}} < T_{\text{upperbound}} \ \textbf{then} \\
18: \ \ \ \ \ m=m+1 \\
19: \ \ \ \ T_{\text{delay}}= T_{\text{delaycur}} \\
20: \ \ \ \textbf{end if} \\
21: \ \ \ \textbf{end for} \\
22: \ \ \ \textbf{end for} \\

\[
\lambda = P_{\Lambda} \lambda 
\]  \hspace{1cm} (23)

The steady-state probability \(\pi(k)\) can be calculated as [30,31].

\[
\pi(k) = \frac{(1-\rho)\rho^k}{1-\rho^{K+1}} 
\]  \hspace{1cm} (24)

Packet blocking probability from the WLAN server is given by

\[
P_k = P_b = \pi(k) = \frac{(1-\rho)\rho^k}{1-\rho^{K+1}} 
\]  \hspace{1cm} (25)

By adaptively adjusted optimal retransmission limit \(M\), after reaching the retransmission limit, the system has maximum network throughput in saturated conditions. The system network can be obtained as
According to Little's Law, packets arrival to the system, is calculated by the average sojourn (delay) time in the queue. \( E[T_{delay}]\) can be expressed as the summation of the average number of idle backoff slots multiplied by the average idle slot duration as a result of backoff at state \((j,i)\), the average busy duration as the result of both successful transmission and failed transmission due to collisions, and also retransmission duration as follows:

\[
S = \frac{(1-P_c)(1-P_s)L_{trans}}{(1-P_{trans})E[T_{suc}] + \frac{P_s - T_{suc}}{P_{trans}} + \frac{P_s - T_{col}}{1-P_c} + [T_{col} + T_{SIFS} + T_{ACK}]}
\]

(26)

4 Results and Discussion

In this section, we evaluate the network performance in an 802.11 WLAN based on our analytical models and demonstrate how to optimize the network performance of IEEE 802.11 DCF network in vehicular network environment. We present the numerical results under various traffic load conditions. The default parameters of WLAN are set as following the current standards of 802.11 DCF protocol: ACK=50\(\mu\)S, SIFS=10\(\mu\)S, DIFS=50\(\mu\)S, and initial backoff window is set as \(CW=32\). Wireless network channel rate is set as 2 Mbps. Packet size is fixed as 1000 byte. We set the traffic jam density \(kj\) as 120 veh/km and free way speed \(V_f\) as 160 km/h. The time slot is set as 50\(\mu\)S.

Fig. 2 shows the system throughput of M/G/K/1 queu under different arrival rates of vehicles in the network, respectively. Offered load rates are \(q_0=0.01\), \(q_1=0.02\), \(q_2=0.05\) for optimal and \(q_3=0.01\) for fixed scheme respectively. At each different arrival rate changes, the mean offered
load also changes with fixed packet size. System throughput increase with the total system capacity increasing when capacity approach to \( C = 2000 \text{Kb/s} \) linearly. This is because, as the system capacity increases, more vehicles would contend for packet transmission in the network, resulting in usage of the system capacity by each vehicle in the whole range of system capacity given. In fixed m scheme, average throughput is lower than that of optimal scheme as fixed m scheme can not adapt the retransmission number to maintain the targeted throughput and requirements.

Fig. 2. Total capacity, (Kbits/s) versus system throughput

Fig. 3 shows the backoff stage number when minimum contention window size increases with vehicle velocity for \( v = 20 \text{km/h}, \ v = 80 \text{km/h}, \text{and } v = 140 \text{km/h} \).

As can be seen in Fig 3, backoff stage number increases when the initial window size increases due to increased delay resulting in more often retransmission attempt and larger adapted retransmission number. Window size is set according to 802.11 DCF maximum retransmission
number \( m = 7 \), whereas in optimal scheme, it is adapted to required targeted delay and throughput settings. Due to increased mobility of vehicles, backoff time, therefore, average delay increase, backoff stage number will be larger than that of non-optimal scheme.

Fig 4 shows the transmission probability when the initial window size increases, with the traffic rate \( \lambda = 1.5 \text{ veh/second} \).

For the default size of initial window size, \( CW = 32 \) transmission probability is 0.01. As initial window size varies from 0 to 80, transmission probability of fixed scheme decreases linearly with the initial window size, while transmission probability of optimal scheme remains in the range of 0.001-0.005, there is optimal \( m \) value for the minimum contention window size for which transmission probability for the mean number of vehicles in the system, is optimized. In non-

![Fig. 3. Minimum contention window size versus mean number of the backoff stage](image)
optimal scheme, variations in the window size cannot be adapted to maximize the transmission probability.

Fig 5 and Fig 6 also depict the impact of initial window size for different traffic rate $\lambda=2$ (vehicle/sec) and $\lambda=4$ veh/sec. For large $\lambda$, the initial window size has larger impact and transmission probability decreases much faster with the increase of initial window size.

At the default size of initial window size, $CW_{\text{min}}=32$, transmission probability for optimal scheme is 0.0075 and 0.0040 for $\lambda=2$ veh/sec and $\lambda=4$ veh/sec respectively. Transmission probability of fixed scheme is much more smaller than that of optimal scheme. Difference for two traffic rates, much increases as traffic rate becomes larger.
Fig 7 shows collision probability performance when vehicles velocity increases. As we can see, when velocity increased, vehicles with high mobility and fast transmission have smaller backoff time, this result in more backoff stages and collision more frequently. As mean backoff stage increases, the collision probability increases, which leads to the reduced mean system throughput.

The number of contending vehicles that can be accommodated by the network is a random variable. Based on M/D/C/C queuing model, probability that there are N vehicles on the roadway segment and under the AP's coverage range can be obtained according to Poisson process with mean vehicle arrival rate $\lambda$, e.g., the traffic flow rate. Fig 8 shows the effect of vehicle density is zero ($\lambda = 0$) and there are vehicles (cars) on the road, flow is zero and a point that shows the lowest value of network size occurs. As vehicle density becomes high, network size also increases. At the other points, that is, highest value of network size is shown, vehicle density is so high that all vehicles stop. Between these two points, network size increase linearly and take its highest value at $k_{jam}=60$ vehicle/km.
Fig 9 shows the average transmission delay with increasing the number of vehicles, $N$. As we can observe, when the number of vehicles increases, the average transmission delay increases in different adapted retransmission limit number, average delay is optimally remains in the range of targeted delay requirements.

When the number of vehicles increases with the traffic rate=1.5 veh/seconds, for the $N=60$, average delay is 0.001 s. As the number of vehicles varies from 0 to 120, average delay of fixed scheme stays linearly in the targeted delay upperbounds (0.5 seconds) with the number of vehicles, while average delay of optimal $m$ scheme remains in the 0.40-0.55 seconds is lower than the fixed $m$ scheme. $m$ is optimized to result in reduced transmission delay and its impact to average delay is obvious.
Fig. 7. Velocity versus collision probability

Fig. 8. Vehicle density versus network size
Fig. 9. The number of vehicles, $N$ versus average delay

Fig 10 also shows the average transmission delay with the increasing the number of vehicles, $N$ for different value of the traffic rate $\lambda=1.5$ vehicle/seconds. For smaller traffic rate, the number of vehicles has a smaller effect and average delay remains in the range of 0.39-0.41 seconds. For the $N=60$, average delay is 0.38 s and 0.58 s for optimal and fixed $m$ scheme respectively.

For higher number of vehicles, adjusting the optimal retransmission limit number $m$, severely effects the average transmission delay and average transmission delay remains at bounded delay limit below (<0.5s). In contrast, the average delay of fixed $m$ scheme remains at above the delay limit.
5 Conclusion

In this paper, we provide an analytical traffic model to investigate the effect of retransmission number $M$ on the performance of vehicular networks. Our derived analytical model novelty evaluates backoff procedure, transmission probability, the number of vehicles that AP can accommodate, average delay (sojourn times) and throughput that a vehicle can transmit a packet by taking into account the impact of maximum retransmission number on the service time of a packet. We used $M/G/1/K$ queuing model and relationship between queuing model and Markov chain model is derived to show the network performance highly sensitive to maximum retransmission number. Based on queuing model, we evaluate the delay and throughput performance optimally under various traffic rate and other system parameter changes. Analytical results show the optimal...
scheme can improve the network delay and throughput performance much better than non-optimal scheme with a fixed retransmission number.

Abbreviations

WLAN: Wireless Local Area Networks, APs: access points, V2N: vehicular-to-network, V2V: vehicular to vehicular, V2I: vehicular-to-infrastructure, V2P: vehicle-to-pedestrian, VANETs: vehicular ad-hoc networks, DCF: Distributed Coordination Function, MAC: medium access control, RSU: Roadside Unit.

Declarations

Availability of data and materials

Data sharing not applicable to this paper since no datasets were analyzed during current study.

Competing interests

The authors declares that they have no competing interests.

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Author’s contributions

A.B. was responsible for investigating the effect of retransmission number M on the performance of vehicular networks and designing the study. Author read and approved the final manuscript.

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Figure Title and Legend:

Figure 1; Markov chain model for the 802.11e backoff process

Figure 2; Total capacity, (Kbits/s) versus system throughput; Total Capacity-System Throughput

Figure 3; Minimum contention window size versus mean number of the backoff stage; Optimal m, Fixed m

Figure 4; Minimum contention window size versus transmission probability, Fixed m, optimal m

Figure 5; Minimum contention window size versus transmission probability, Fixed m Optimal m

Figure 6; Minimum contention window size versus transmission probability; Fixed m Optimal m

Figure 7; Velocity versus collision probability; Upper Bound, Finite, optimal
Figure 8; Vehicle density versus network size

Figure 9; The number of vehicles, N versus average delay, Finite optimal

Figure 10; The number of vehicles, N versus average delay, Fixed optimal.