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Vehicles Communication and Connectivity using Persistent Carrier Sensing Multiple Access Protocol

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Abstract: This paper investigates the effectiveness of using P-persistent carrier sensing multiple access (P-Persistent CSMA) on vehicular connectivity as vehicles dynamically form temporary communication networks using simulation and mathematical modelling. In the connected and autonomous environment, effective and efficient connectivity between vehicles (V2V) and between vehicles and infrastructure (V2I) is critical. The simulation was performed in MATLAB and included the investigation of the effect of vehicular density, probability value change, and increase in Backoff time, and change in data frame size. The results showed that as vehicular density, probability, and data frame size increased, throughput decreased as data traffic increased, whereas as Backoff time and probability increased, throughput increased. Furthermore, as data size increases with decreasing probability level, channel utilization improves. Based on these findings and the derived mathematical expressions, a proposed dynamic and adaptive model is presented, allowing for maximum throughput while minimizing collisions. This is accomplished by equating four mathematical expressions and substituting them using iteration to achieve a balanced and optimal level of communication channel utilization by dynamically adjusting the three main parameters under consideration as a function of increasing vehicular density (P-Persistent probability level, Backoff time, and data frame length). To achieve such dynamical and adaptive optimization, four mathematical expressions are used. The resulting model is promising and will improve the efficiency of non-adaptive conventional P-Persistent CSMA. The presented work proved to increase the effectiveness of the conventional p-persistent technique using a multi-dimensional parameter correlation, which is more effective than weighted, slotted, or adaptive P-Persistent approaches.

Keywords: P-persistent, Connected vehicles, Intelligent transportation systems, Network connectivity, Probability, CSMA, Backoff, Wireless communication.

1. Introduction

Advanced communication technology will be used in future vehicles and roads to improve driving safety, efficiency, and environmental sustainability. The safety improvements will mostly be attained through informing the driver of important safety information via applications.

In order to significantly improve safety, mobility, and the environment, vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications involve the wireless interchange of data among and between infrastructure and vehicles traveling in the same area. Additional associated pedestrian-related capabilities are referred to as "vehicle-to-pedestrian" (V2P) communication. These communication capabilities will make it possible to develop a wide range of safety applications and systems for both infrastructure and vehicles. In order to provide active safety applications, these systems enable communication between all on-road vehicles and the surrounding environment, as well as with pedestrians and other vehicles. These technologies provide a network of communication that can be used to enhance mobility and environmental effects [1-7].

With the recent rapid advancements in wireless communications, particularly as an intelligent transportation system (ITS), vehicle-to-vehicle (V2V) communications have attracted significant attention. By exchanging vast amounts of information using basic safety messages (BSMs) among the vehicles in the vehicular ad-hoc network (VANET), it is seen to be a solid proposal to reach the desired degree of traffic safety [8, 9].

VANETs possess dynamic and mobile topology, which need to be utilized to provide safe and comfortable driving through vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. High mobility, the restriction of a dynamic road network topology, unpredictable network size, and infrastructure support are only a few of the challenges for using VANETs. Such variables would affect communication and accessibility strategies as they affect scalability, recurrent information exchange, time-critical communication, wireless medium of communication, and data exchange efficiency [10-12].

In general, VANET applications can be divided into two groups: safety-based applications (traffic management and accident prevention) and non-safety-based applications (services such as parking and congestion avoidance).

Communication using VANETs has been regulated by the usage of dedicated short range communication (DSRC) under IEEE 802.11p protocol, wireless access in vehicular environments (WAVE) under IEEE 1609 protocol, and 5G long-term evolution (LTE). Dedicated frequency bands have been adopted for vehicular communication under intelligent transportation systems (ITS). The communication spectrum is divided using single channel and multi-channel media access control (MAC). The multi-channel MAC handles load balancing and collision avoidance by offering various channel access mechanisms, whereas the single-channel MAC concentrates on resource allocation [13-17].

The medium access control (MAC) protocol was designed to support a variety of VANET of both safety and non-safety applications. MAC protocols utilized are referred to as contention-based MAC protocols if cars access the channel using the carrier sensing mechanism to exchange their data. The fundamental drawback of this strategy is that when nearby cars simultaneously send their data, packet collisions take place at the receiver. Contention-free MAC techniques are characterized by permitting just one vehicle from the neighbourhood to access the channel at any given time if no collision data is transmitted. The need to save the schedule table and time synchronization is a drawback of this method. There has been a tremendous amount of work focusing on VANETs utilizing IEEE 802.11p, the default standard for distributed V2V communications. The IEEE 802.11p standard is a contention-based MAC protocol method using carrier-sense multiple access with collision avoidance (CSMA/CA) to avoid interference and collisions between different nodes [18-20].

The core of modern wireless media access control systems are the CSMA-based algorithms. The fundamental CSMA methods have undergone a number of improvements over the past few decades, mostly to facilitate collision avoidance. The p-persistent model's potential for studying the behaviour of numerous CSMA protocols has lately initiated renewed interest in the performance analysis of the p-persistent CSMA. A crucial performance indicator is the p-capacity. CSMA's It determines the maximum channel utilization achievable in the p-persistent CSMA under different probabilities [21-24].

It is established that a node trying to send information will contend with other nodes for the shared channel according to the p-persistent CSMA, transmits data with probability P if the channel is idle, and postpones transmission with the probability (1-p) if the channel is busy. In general, MAC protocols for wireless networking need high bandwidth. In general, the percentage of channel bandwidth utilized for successful transmissions is an indication of the overhead cost by the media access protocol coordinating transmission among contending nodes the nodes. Channel utilization in p-persistent CSMA is greatly affected by the probability value, which represents the persistence level of the protocol [25-30].

2. Related work

In the medium access control (MAC) protocol known as carrier-sense multiple access (CSMA), a node first confirms that there is no other traffic present before broadcasting on a shared transmission medium. In accordance with CSMA, a transmitter first checks to if another transmission is already in progress using a carrier-sense method. It checks to see if a carrier signal from another node is there before attempting to broadcast. If a carrier is detected, the node waits for the current transmission to finish before starting a new one. Multiple nodes may send and receive on the same media in turn using CSMA [31-35].

Different CSMA variants employ various methods to choose when to begin transmission onto the shared medium. These algorithms' aggressiveness or persistence in commencing transmission is a crucial differentiator. A more aggressive algorithm can start transmitting more rapidly and use a larger portion of the medium's available bandwidth. Usually, this comes with a higher chance of colliding with other transmitters [36-40].

An aggressive transmission algorithm is 1-persistent CSMA. The transmitting node detects whether the transmission medium is idle or busy when it is prepared to send. If idle, it communicates right away. If busy, it constantly senses the transmission medium until it is idle, at which point it sends the frame of the message unconditionally (with probability equals to 1). If there is a collision, the sender waits for an arbitrary amount of time before trying the same method again.

A non-aggressive transmission algorithm is non persistent CSMA. The transmitting node detects whether the transmission medium is idle or busy when it is prepared to transfer data. If idle, it communicates right away. If the channel is busy, it skips straight to the 1-persistent CSMA's final random waiting step before restarting the entire logic cycle once more. This avoids monitoring the busy channel repeatedly while trying to send a message, hence the name. This method, compared to 1-persistent, results in a greater initial delay but lowers the likelihood of collision and increases medium throughput overall.

Between the 1-persistent and non-persistent CSMA access modes lies the P-persistent algorithm. The transmitting node detects whether the transmission medium is idle or busy when it is prepared to transfer data. If idle, it communicates right away. If it's busy, it continuously senses the transmission channel until it is idle, at which point it transmits with probability p. The node waits until the following time slot is open if it decides not to transmit (the likelihood of this happening is 1-p). It transmits again with the same probability p if the transmission medium is not busy. This probabilistic hold-off continues until the frame is eventually transferred or the medium is discovered to be busy once more (some other node has already started transmitting). The node repeats the entire logic cycle (which began with sensing the transmission medium for idle or busy). In CSMA/CA systems, such as Wi-Fi and other packet radio systems, p-persistent CSMA is employed.

The conventional P-persistence techniques could result in a data traffic congestion problem when broadcasting over vehicular ad hoc networks. Three modified techniques are developed to counter such effect:

- Weighted p-persistence
- Slotted p-persistence
- Adaptive p-persistent

Vehicular density and distribution have a significant impact on how well the slotted p-persistence system performs. The slotted p-persistence technique can therefore result in a lengthy wait before rebroadcasting in a sparse network when no cars are present in the prior slots. On the other hand, in a congested network, several vehicles will attempt to rebroadcast concurrently in the same slot, leading to data traffic congestion [41-43].

The slotted p-persistence scheme, which is based on estimating the vehicular density, has already been improved by a number of methods.

A dynamic broadcast technique to adjust the rebroadcast probability p is researched. Meanwhile, other approaches proposed a plan to dynamically change the number of spaces in accordance with vehicular density. However, in actual highway circumstances, the density of the vehicles fluctuates continually, making it impossible to distribute them uniformly throughout the slots. As a result, neither strategy can eliminate the needless waiting period before rebroadcasting caused by empty slots, or slots with no vehicles [44-46].

The relative distance between the vehicle and the broadcaster is used to compute the rebroadcast probability p of a vehicle using the weighted p-persistence approach. In this system, vehicles that are further away from the transmitter are given a larger probability. In the meantime, the broadcaster's transmission range is divided into a predetermined number of slots in the slotted p-persistence scheme, and a vehicle rebroadcasts the message using the predetermined probability p at the designated time slot according to its location within the slots in the transmission range.

Each vehicle calculates the waiting period before broadcasting using data from the global positioning system (GPS). For the majority of multi-hop VANET applications, it is suggested that the slotted p-persistence scheme may further lower the broadcast redundancy and packet loss ratio when compared with the weighted p-persistence scheme.

P values are modified in adaptive p-persistent CSMA in accordance with the channel circumstances. The same methods employed in link adaption techniques in IEEE 802.11 protocol, can be utilized to obtain the channel conditions. Likelihood of a successful packet. At high data rates, it is reported that throughput decreases by two thirds with very high packet error rates. Using adaptive p-persistent showed that it can increase total throughput by about one fourth, even under bad channel conditions, preventing the deterioration of a service [47-50].

So far, an optimizing and equating mathematical model is not clearly presented to enable correlation of different data exchange parameters (Backoff time,

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Probability, Data frame size, and vehicular density), which this work attempts to present.

For conventional p-persistent, high p values can cause large collisions, while low p values expected to underutilize available bandwidth resulting in a semi-idle channel. Thus to reach acceptable utilization of communication channel, an optimum p value needs to be reached. This could be achieved by controlling the number of nodes sharing the channel at any given time. Hence, optimal selection of p would become realistic. Another approach would be to adapt p to the existing number of nodes. Thus, using the settings above would enable through simulation to investigate optimization of p and backoff values in relation to increasing number of vehicles, and the overall effect on throughput as a function of data traffic.

Both too low and too high p values reduce throughput. The likelihood of multiple stations accessing a channel at once is decreased if p is low. If p is too low, though, it can lead to empty time slots and decreased throughput because fewer stations will actually send. Stations are more likely to transmit when p is high. However, there is a greater chance that multiple stations may try to transmit at once, which raises the likelihood of a collision and lowers throughput.

In this paper a detailed characterization and analysis of the efficiency of vehicular connectivity using P-Persistent is investigated through relating traffic to throughput, and analyse effect of variation of parameters such as number of vehicles, backoff time, number of slots, and data size (Frame Length).

This approach would result in using conventional P-Persistent with low efficiency and effectiveness and produce Balanced-P-Persistent with higher efficiency and ability to be correlated to different parameters at the same time, resulting in a more effective communication channel and more intelligent approach to channel utilization.

The main points of contribution of this work are:

- Simulation of vehicular communication with different number of vehicles (vehicular density).
- Analysis of effect of vehicular density on the relationship between data traffic and throughput.
- Analysis of effect of P-Persistent level probability on the relationship between data traffic and throughput.
- Analysis of effect of increasing Backoff time on the relationship between data traffic and throughput.
- Analysis of effect of data frame length on the relationship between data traffic and throughput.
- Establishing mathematical expressions relating vehicular density, P-Persistent level probability, Backoff time, data frame length to data traffic and throughput.
- Establishing mathematical expression that equate all considered parameters and results in obtaining optimum values, which when used, will increase communication channel utilization for vehicular connectivity significantly as it allows balancing of all parameters at a point of optimization.

Comparing the proposed approach to the three modified (more intelligent) P-Persistent techniques, the following is realized:

1. In the case of **Weighted P-Persistent** techniques, which is considered state-of-the-art modified P-Persistent, the relative distance between the vehicle and the broadcaster is used to compute the rebroadcast probability p of a vehicle in the weighted p-persistence scheme. Under this system, vehicles that are further away from the transmitter are given a larger probability. In this work with the proposed **balanced-P-Persistent** technique, the probability P is correlated to vehicular density (V), Backoff time (τ), and data size (L). This is a multi-dimensional correlation with dynamic balancing and proves a better and more effective approach.
2. In the case of **slotted P -Persistent**, which supposed to enhance the performance of the adaptive P-Persistent technique, the slotted p-persistence technique divides the broadcaster's transmission range into a predetermined number of slots, and a vehicle rebroadcasts the message using the predetermined probability p at the assigned time slot based also based on its location within the transmission range. Each vehicle computes the waiting time before transmission. When compared to the weighted p-persistence scheme, the slotted p-persistence approach will further reduce broadcast redundancy and packet loss ratio and have better communication effectiveness. However, compared to the proposed **Balanced P-Persistent**, the technique can be utilized with more parameters than just location. Vehicular density is a very important

Table 1. Nomenclature

Symbols/ Acronyms	Meaning
V	Nodes Number: Number of vehicles that generate packets.
P	Persistent level probability
Backoff time (τ)	Backoff value that a node must wait before attempting new transmission (Mean delay (in slots) for a successfully transmitted and acknowledged packet).
S	Throughput of the P-Persistent Carrier Sensing Multiple Access protocol.
G	Normalized available traffic, with retransmissions included.
R	Ratio of Average S to Average G
N	Number of Slots
L	Data Frame Length.
$S_{average}$	Average throughput of the P-Persistent Carrier Sensing Multiple Access protocol.
$G_{average}$	Average normalized available traffic, with retransmissions included.
α and β	Optimizing parameters relating average data traffic to number of vehicles.
λ and κ	Optimizing parameters relating average throughput to number of vehicles.
Ψ and Φ	Optimizing parameters relating average throughput to average data traffic as a function of vehicular density.
η and δ	Optimizing parameters relating average data traffic to persistent probability.
ϑ and ε	Optimizing parameters relating average throughput to persistent probability.
Θ and Ω	Optimizing parameters relating average throughput to average data traffic as a function of persistent probability.
μ and ς	Optimizing parameters relating average data traffic to backoff time (τ).
σ and χ	Optimizing parameters relating average throughput to backoff time (τ).
ρ and Λ	Optimizing parameters relating average throughput to average data traffic as a function of backoff time (τ).
ν and ξ	Optimizing parameters relating average throughput to average data traffic as a function of data size (L).

parameter to consider together with Backoff time and data size.

3. In the case of **adaptive P-Persistent** technique, is a variant of P-Persistent CSMA with the difference that the probability p varies depending on the traffic condition, whereas in p-persistent CSMA it is constant, in adaptive P-Persistent approach, p is defined as the Gaussian complementary distribution function. Compared to the proposed **Balanced P-persistent**, the adaptive approach looks at data traffic in terms of communication channel quality and interface, while the proposed technique in this work takes this into account in addition to other parameters.

Thus the proposed technique as will be presented should prove to be a more effective and efficient implementation of the conventional P-Persistent.

The rest of this paper is divided as follows:

1. Related work: Describing the applicability of random access and carrier sensing multiple access technique to vehicular communication.
2. Methodology: Describing research approach and the simulation scenario with considered parameters.
3. Results and discussion: Discussing and analysing MATLAB simulation results and how channel efficiency can be improved for vehicular communication.
4. Conclusions: Summarizing the achieved end

results.

3. Methodology

This work considers a dynamically changing number of vehicles communicating by forming temporary vehicular networks (VANETS) and exchanging basic safety messages (BSMs). The proposed approach of this work is to consider effect of the following:

1. Variable number of vehicles
2. Different data frame lengths
3. Changing in P-Persistent slot probability

Such effect is analysed in terms of normalized offered traffic (G) and throughput (S). The considered vehicular network has the following properties on which the simulation scenarios are carried out:

1. Synchronized in the sense that the slot bounds of all vehicles are aligned.
2. Each vehicle (node) uses the same protocol and generates data frame with a probability P per slot.
3. Each frame is assigned an N number of slots.
4. An error is assumed in the transmission if two (or more) stations overlap.
5. It is assumed in the simulation that each station knows at the end of transmission if it is successful.
6. In case of an erroneous transmission, each node will wait for a random time drawn from a dynamically changing number of slots (specified in the simulation) at the end of its own transmission and repeat the protocol.

The work simulates p-persistent using MATLAB in order to investigate effect of the following parameters on the relationship between traffic and throughput:

1. Number of vehicles (V)
2. Backoff time (τ)
3. Persistent Level Probability (P)
4. Data Frame Length (L).

Table 1 present definition for all used variables in the simulation and mathematical modelling.

4. Results and discussion

4.1 Effect of number of vehicles (V)

Figs. 1 to 5 show the relationship between S and G for an incrementing number of vehicles as a function of the following parameters:

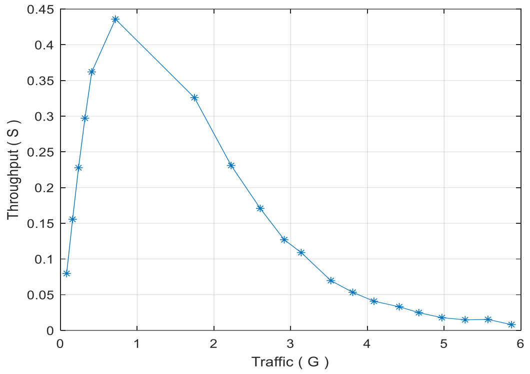

Figure. 1 Relationship between throughput and traffic for V=20

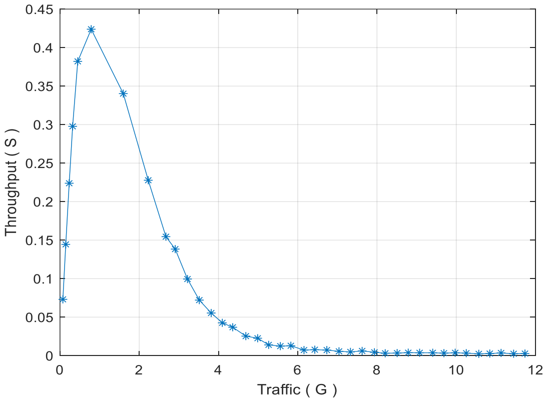

Figure. 2 Relationship between throughput and traffic for V=40

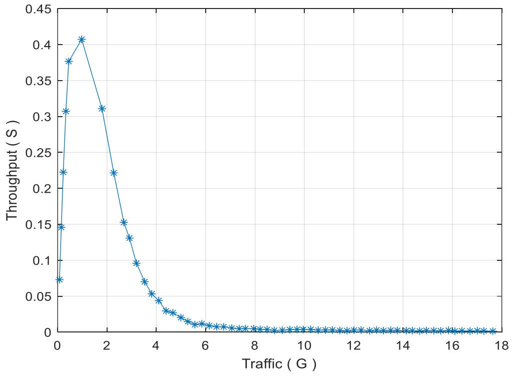

Figure. 3 Relationship between throughput and traffic for V=60

1. Number of slots (N) = 12000
2. Data frame length L= 15
3. Persistent level probability (P) = 0.5
4. Backoff value (τ) = 20 Slots.

Analysis of Figs. 1 to 5 is presented in Figs. 6 to 8. Fig.6 shows the relationship between average G and number of vehicles (V). From the plot, an evident increase in G is observed as vehicular connectivity

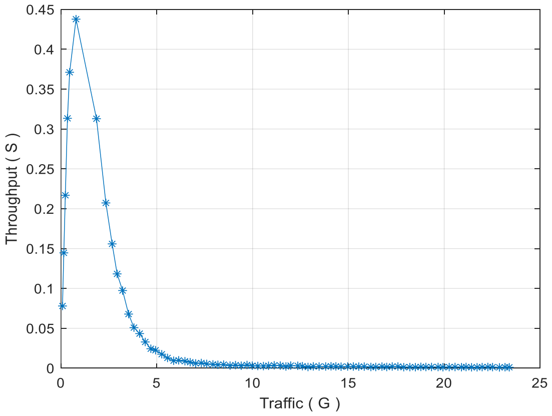

Figure. 4 Relationship between throughput and traffic for V=80

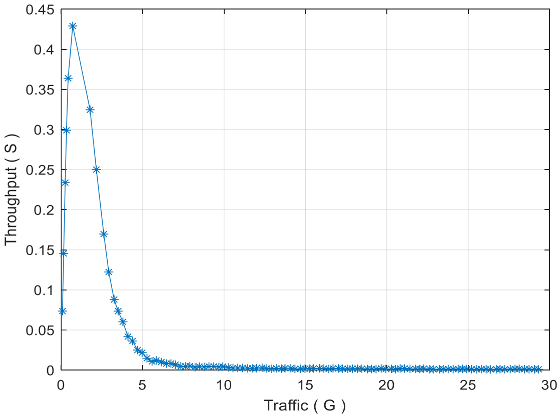

Figure. 5 Relationship between throughput and traffic for V=100

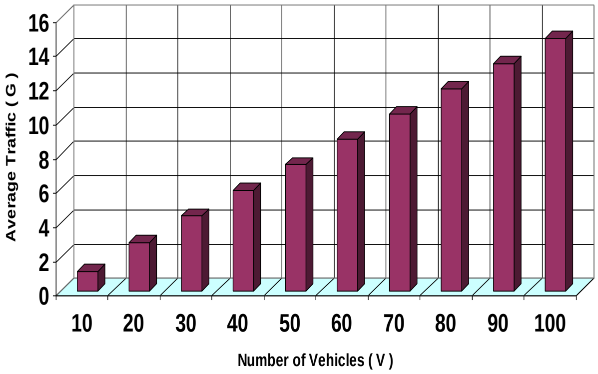

Figure. 6 Average traffic as a function of increasing number of vehicles

increases. The relationship is proved to follow power law as shown in Eq. (1).

$$G_{Average} = \alpha V^{\beta} \tag{1}$$

Where;

$$\alpha \geq 0.1$$
$$\beta \leq 1.1$$

The power law increases in average traffic as a function of V is related to the increase in the number of nodes with data to send, which expect to result in more collisions and less throughput. Thus an optimum and dynamically balanced channel communication is needed. Such optimization will require further analysis as will be seen later.

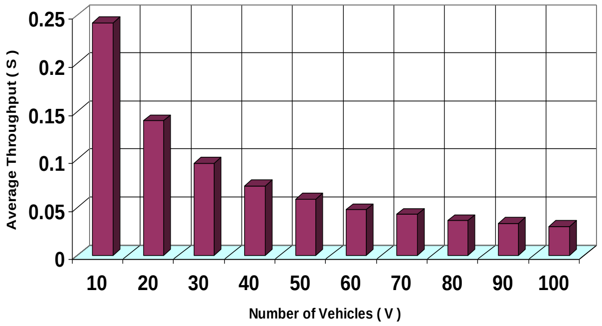

Figure. 7 Average throughput as a function of increasing number of vehicles

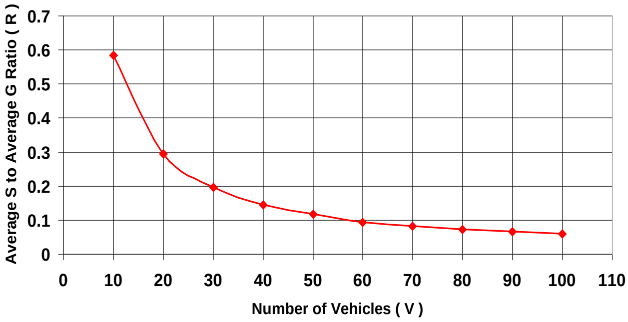

Figure. 8 Ratio (R) as a function of increasing number of vehicles

Fig. 7 shows the relationship between average S and number of vehicles (V). The plot shows a gradual decrease in the average value of S as the number of communicating nodes increases. The mathematical model is shown in Eq. (2).

$$S_{Average} = \lambda V^{-\kappa} \tag{2}$$

Where;

$$\lambda \geq 2$$
$$\kappa \geq 0.9$$

The evident and gradual reduction of average throughput as a function of increasing number of vehicles is expected, due to increase in data traffic and possible increase in the probability of data collision.

To establish effect of traffic on throughput as a function of increase in vehicular connectivity, Fig. 13 shows a plot of the ratio between S and G as a function of changing number of communicating vehicles. The plot clearly shows a power decrease of the ratio of average S to average G as a function of

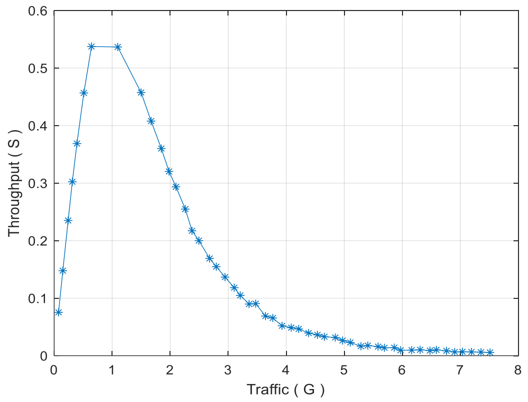

Figure. 9 Relationship between throughput and traffic for P=0.2

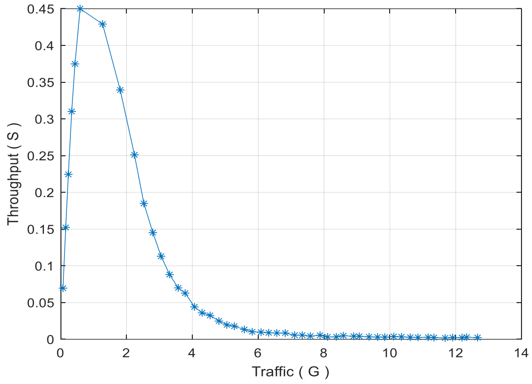

Figure. 10 Relationship between throughput and traffic for P=0.4

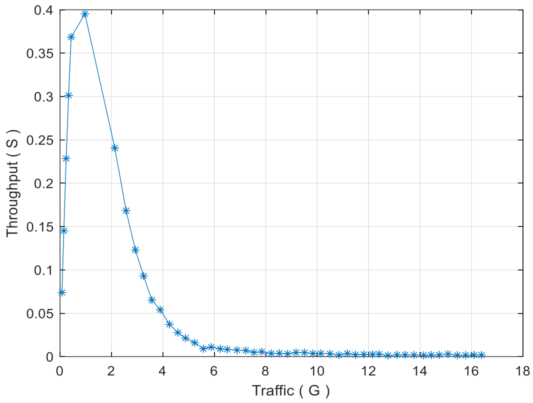

Figure. 11 Relationship between throughput and traffic for P=0.6

increasing number of vehicles. The relationship is described in Eq. (3). Such observation supports the need for a dynamic, adaptive and optimizing condition to be reached.

The normalized curve in Fig. 8 shows effect of increasing data traffic as a function of increasing number of vehicles on anticipated throughput. This plot gives clear indication to the need to modify and adapt the P-Persistent protocol to enable higher throughput levels even with increasing vehicular density.

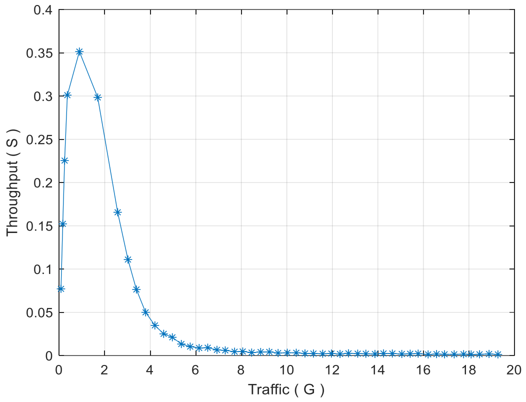

Figure. 12 Relationship between throughput and traffic for P=0.8

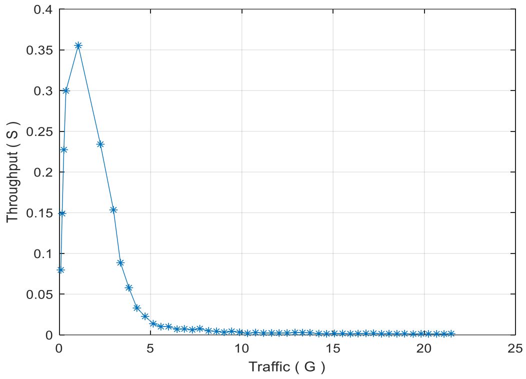

Figure. 13 Relationship between throughput and traffic for P=1.0

$$\boldsymbol{R = \left(\frac{S_{Average}}{G_{Average}}\right) = \Psi V^{-\Phi}} \tag{3}$$

From Eqs. (3) and (4) is obtained.

$$\boldsymbol{S_{Average} = G_{Average}\left(\Psi V^{-\Phi}\right)} \tag{4}$$

4.2 Effect of probability

Figs. 9 to 13 show the relationship between S and G for an incrementing the P value as a function of the following parameters:

1. Number of slots (N)= 12000
2. Data frame length (L) = 15
3. Nodes number: Number of vehicles that generate packets (V) = 50
4. Backoff (τ) = 20 Slots

Figs. 14 to 16 highlight effect of change in probability value on both G and S. Fig. 14 show an increase in average traffic as a function of increase in probability, with Eq. (5) showing the power law mathematical representation. The increase in average traffic is due to increase in persistent level of transmitting nodes, with higher expectation of

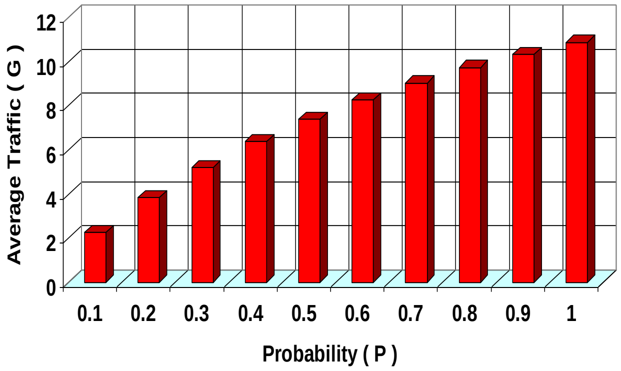

Figure. 14 Average traffic as a function of increasing number probability

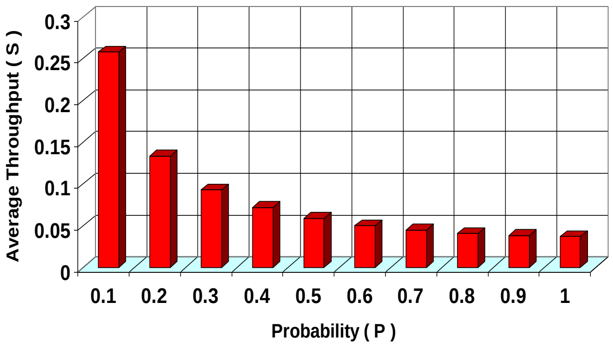

Figure. 15 Average throughput as a function of increasing number probability

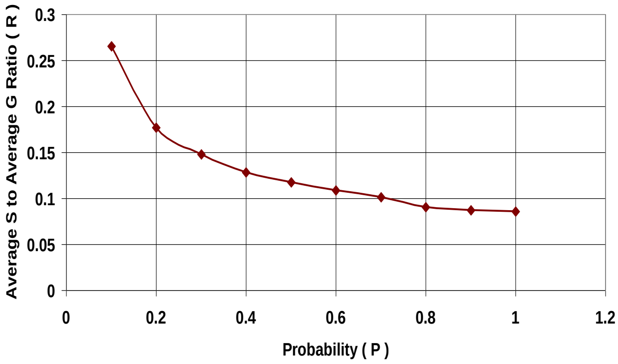

Figure. 16 Ratio (R) as a function of increasing probability

transmission. This will effectively ramps up anticipated data traffic to higher levels. This observation supports the need to control the persistent level probability in correlation with vehicular density, previously discussed, such that it results in an optimum utilization of communication channels, without increase in probability of collision.

$$G_{Average} = \eta P^{\delta} \tag{5}$$

Where;

$$\eta \geq 11$$
$$\delta \leq 0.7$$

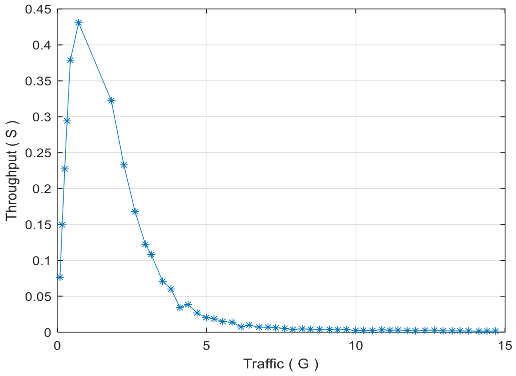

Figure. 17 Relationship between throughput and traffic for backoff =20

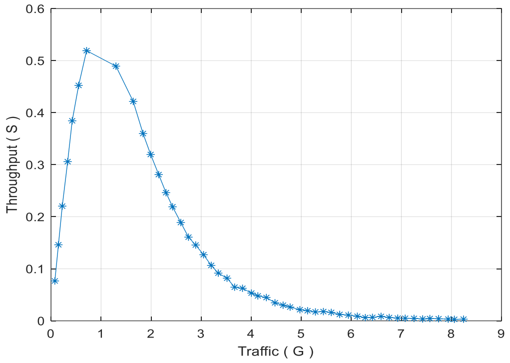

Figure. 18 Relationship between throughput and traffic for backoff =100

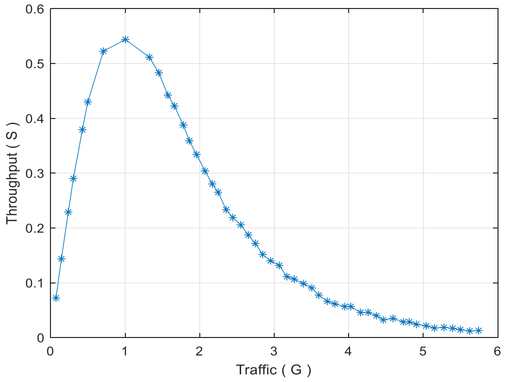

Figure. 19 Relationship between throughput and traffic for backoff =180

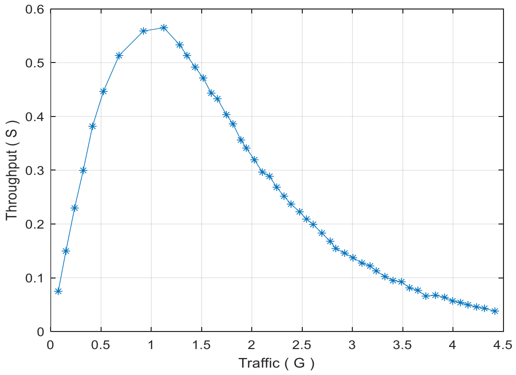

Figure. 20 Relationship between throughput and traffic for backoff =260

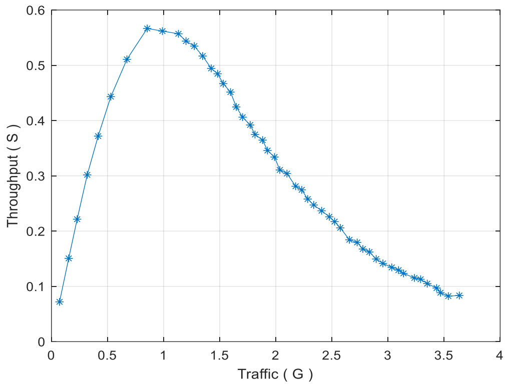

Figure. 21 Relationship between throughput and traffic for backoff =340

Fig. 15 shows a decrease in average throughput as a function of increasing probability, with Eq. (6) showing the mathematical representation. This is due to the increase in data traffic, due to increased probability of transmission.

$$S_{Average} = \vartheta P^{-\varepsilon} \tag{6}$$

Where;

$$\vartheta \geq 0.03$$
$$\varepsilon \leq 0.9$$

Fig. 16 show a measuring effect of increasing probability value on the ratio between average S and average G. Eq. (7) shows the mathematical model. The plot shows a decrease in the ratio (R) as a function of increasing probability.

$$R = \left(\frac{S_{Average}}{G_{Average}}\right) = \Theta P^{-\Omega} \tag{7}$$

From Eqs. (7) and (8) is obtained.

$$S_{Average} = G_{Average}\left(\Theta P^{-\Omega}\right) \tag{8}$$

4.3 Effect of Backoff time (τ)

Figs. 17 to 21 show the relationship between S and G for an incrementing backoff time as a function of the following parameters:

1. Number of Slots (N) = 12000
2. Data Frame Length (L) = 15
3. Persistent level probability (P) =0.5
4. Nodes Number: Number of vehicles that generate packets (V) = 50

Fig. 22 shows effect of increasing backoff time on average traffic. The plot shows a steady decrease in average G, represented as in Eq. (9). The reduction in data traffic consistent with increasing time intervals before transmission or re-transmission. This is also related to lowering probability persistent level for a fixed vehicular density. This observation shows the need to optimize backoff time in correlation with vehicular density and persistent level probability in order to achieve best network efficiency.

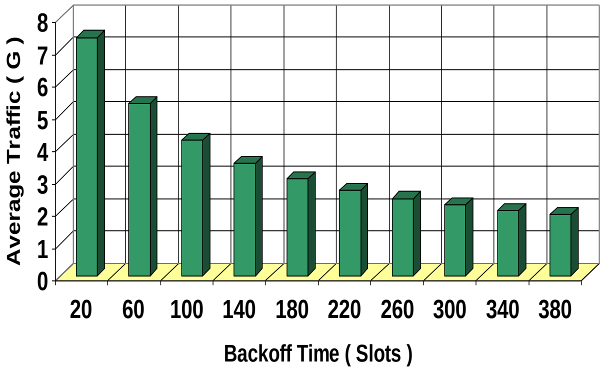

Figure. 22 Average traffic as a function of increasing backoff

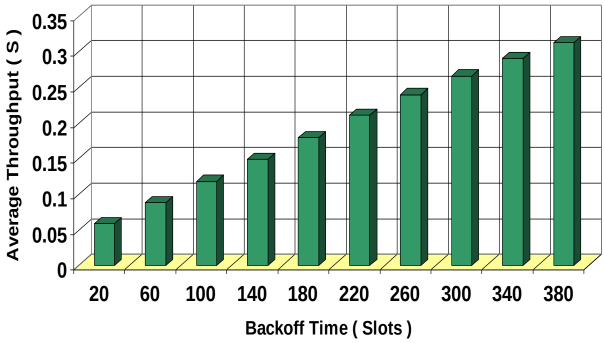

Figure. 23 Average throughput as a function of increasing backoff

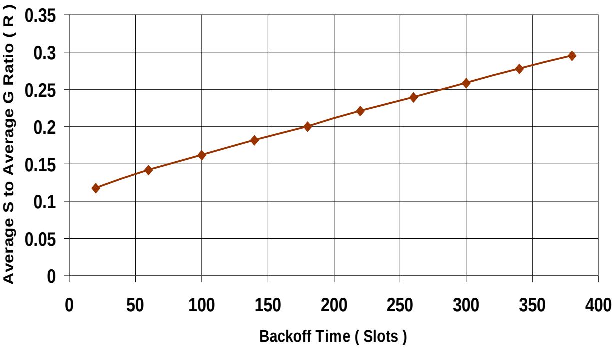

Figure. 24 Ratio (R) as a function of increasing backoff

$$G_{Average} = \mu \tau^{-\varsigma} \tag{9}$$

Where;

$$\mu \geq 35$$
$$\varsigma \leq 0.5$$

Fig. 23 shows effect of increasing backoff time on average throughput. The plot shows a steady increase in average S, represented as in Eq. (10). The tendency here is opposite to the previous two cases (increasing v, and increasing P). The increase in S is due to the decrease of G, as there are more available slots for nodes to use in their connectivity.

$$S_{Average} = \sigma\tau^{\chi} \qquad (10)$$

Where;

$$\sigma \leq 0.01$$
$$\chi \leq 0.6$$

Fig. 24 shows effect of increasing backoff time on the relationship between G and S through the ratio (R). A clear increase in throughput in observed as the backoff time increases. The mathematical relationship is shown in Eq. (11).

$$R = \left(\frac{S_{Average}}{G_{Average}}\right) = \rho\tau^{\Lambda} \qquad (11)$$

From Eqs. (11) and (12) is obtained.

$$S_{Average} = G_{Average}\left(\rho\tau^{\Lambda}\right) \qquad (12)$$

4.4 Effect of frame length (data size and channel utilization)

Figs. 25 to 32 show the relationship between S and G for different data frame size (L) and persistent level probability (P) values, as a function of the following parameters:

1. 1. Number of slots (N) = 12000
2. 2. Nodes number: Number of vehicles that generate packets (V) =50
3. 3. Backoff value (τ) = 20 Slots

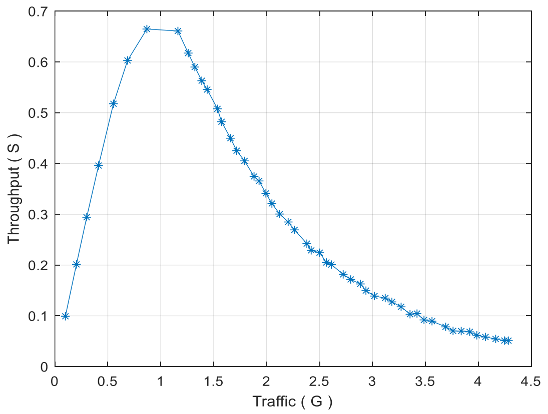

Figure. 25 Relationship between throughput and traffic for L= 20, P=0.1.

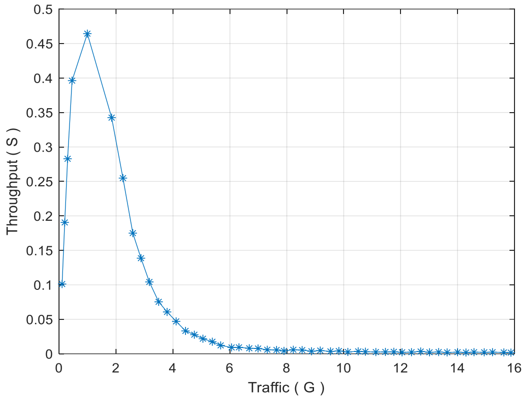

Figure. 26 Relationship between throughput and traffic for L= 20, P=0.5.

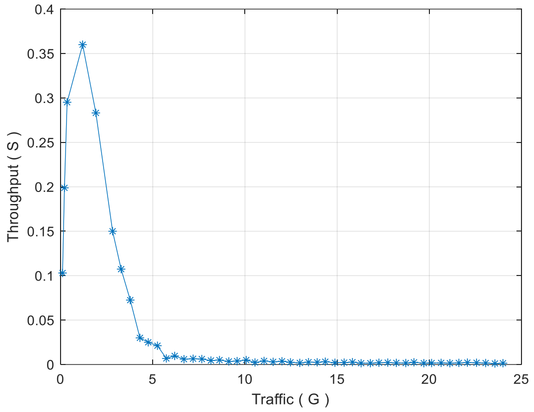

Figure. 27 Relationship between throughput and traffic for L= 20, P=1.0

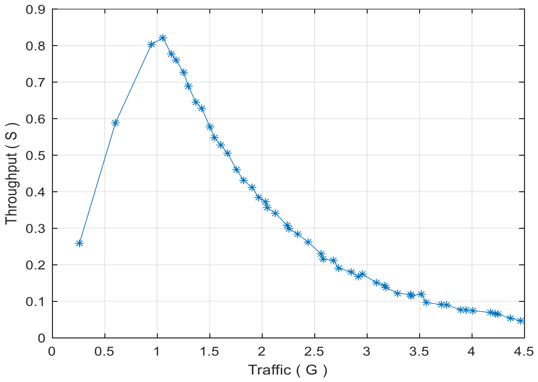

Figure. 28 Relationship between throughput and traffic for L= 60, P=0.1

Fig. 34 shows effect of increasing data size and P-Persistent level on the relationship between G and S through the ratio (R). A clear decrease in throughput in observed as the P value increases. The mathematical relationship is shown in Eq. (13). The plots in Fig. 34 clearly indicate that at small probability, traffic is much lower, thus throughput would be higher, with less collisions at high data levels (frame size L). This indicates the importance of optimizing frame size as a function of vehicular density.

As the probability values increases, more expected traffic to be generated, which reduces possible throughput as probability of collisions increases, which when correlated with bigger data size would lead to lowering the throughput significantly in addition to anticipated increase in collisions as a function of P.

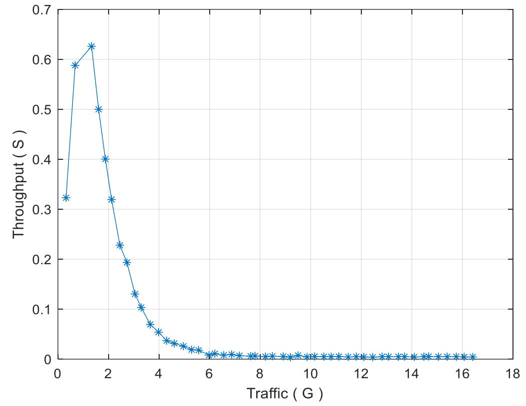

Figure. 29 Relationship between throughput and traffic for L= 60, P=0.5

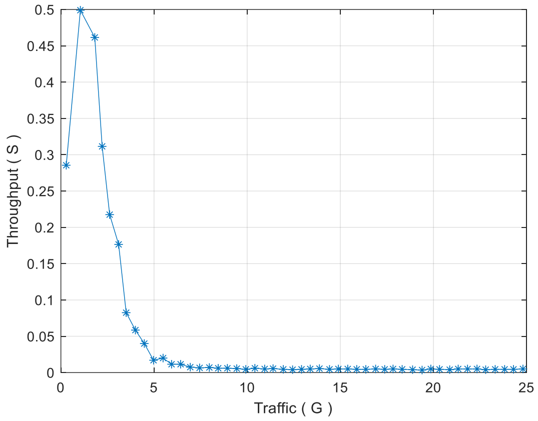

Figure. 30 Relationship between throughput and traffic for L= 60, P=1.0

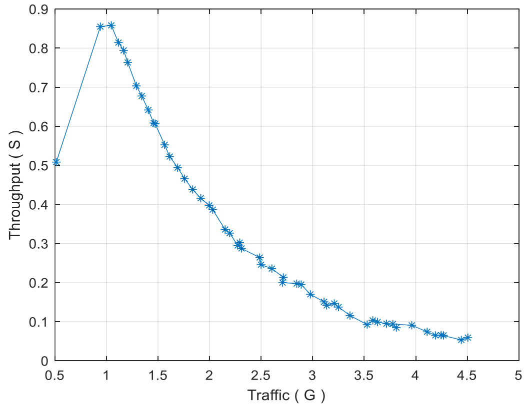

Figure. 31 Relationship between throughput and traffic for L= 100, P=0.1

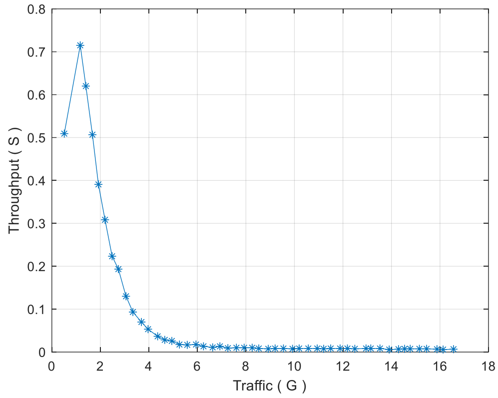

Figure. 32 Relationship between throughput and traffic for L= 100, P=0.5

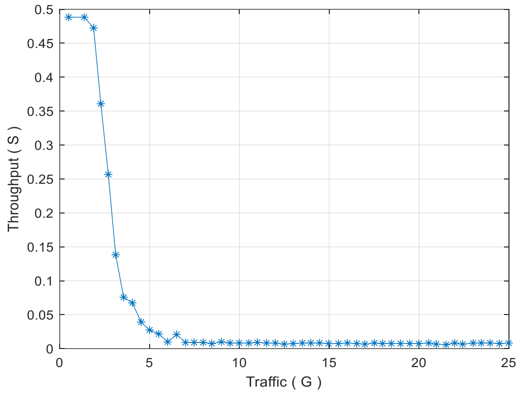

Figure. 33 Relationship between throughput and traffic for L= 100, P=1.0

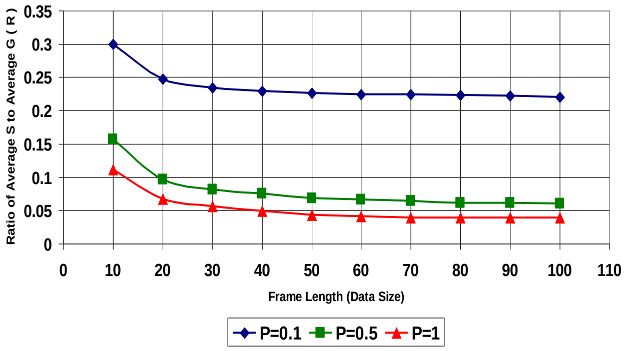

Figure. 34 Effect of P-persistent level on effective communication of connected vehicles

$$\boldsymbol{R} = \left(\frac{\boldsymbol{S_{Average}}}{\boldsymbol{G_{Average}}}\right) = \boldsymbol{\nu L^{-\xi}} \quad (13)$$

From Eqs. (13) and (14) is obtained.

$$\boldsymbol{S_{Average}} = \boldsymbol{G_{Average}}\left(\boldsymbol{\nu L^{-\xi}}\right) \quad (14)$$

Where;

$$\boldsymbol{\nu \leq 0.37}$$
$$\boldsymbol{\xi \leq 0.45}$$

The optimum throughput can be obtained by equating Eqs. (3), (7), (11), and (14) in order to achieve equilibrium and thus select the appropriate parameters to achieve better throughput and lower collisions per connected nodes over a utilized communication channel. Using this approach, the result is presented in Eq. (15).

$$\boldsymbol{R = \left(\frac{S_{Average}}{G_{Average}}\right) = \Psi V^{-\Phi} = \Theta P^{-\Omega} = \rho\tau^{\Lambda} = \nu L^{-\xi}} \tag{15}$$

From Eq. (15), the following is obtained:

$$\boldsymbol{V^{-\Phi} = \frac{\Theta P^{-\Omega}}{\Psi} = \frac{\rho\tau^{\Lambda}}{\Psi} = \frac{\nu L^{-\xi}}{\Psi}} \tag{16}$$

$$\boldsymbol{P^{-\Omega} = \frac{\Psi V^{-\Phi}}{\Theta} = \frac{\rho\tau^{\Lambda}}{\Theta} = \frac{\nu L^{-\xi}}{\Theta}} \tag{17}$$

$$\boldsymbol{\tau^{\Lambda} = \frac{\Psi V^{-\Phi}}{\rho} = \frac{\Theta P^{-\Omega}}{\rho} = \frac{\nu L^{-\xi}}{\rho}} \tag{18}$$

$$\boldsymbol{L^{-\xi} = \frac{\Psi V^{-\Phi}}{\nu} = \frac{\Theta P^{-\Omega}}{\nu} = \frac{\rho\tau^{\Lambda}}{\nu}} \tag{19}$$

By using Eqs. (16) to (19), an optimum and balanced communication channel can be obtained, whereby an acceptable level of throughput as a function of data traffic is achieved. This new approach (balanced P-persistent), is a multi-dimensional modelling and simulation approach, which will provide a unique, dynamic and comprehensive approach to utilize an initially conventional P-persistent technique with mainly inefficient characterisitics and produce a highly efficient and effective vehicular communication technique.

5. Conclusions

The work explores the characteristics of P-persistent through simulation and suggests a novel strategy to permit lower collisions and higher throughput. In order to enable adaptive alteration of parameters related to vehicle density, backoff time, probability value, data frame length. The work offered an equating approach. As a result, collision levels can be reduced, throughput can be increased, and communication channels can be used more effectively.

Overall, through characterisation, analysis, and model presentation, the simulation and analysis showed to be a useful starting point for the construction of an adaptive and dynamic p-persistent algorithm.

If actual measurements were obtained and compared to simulations, this study may be further improved. In order to demonstrate the efficiency of the mathematical model offered, it must also be used in a variety of real-world situations. Future investigations and simulation are needed to further optimize the new proposed method in order to effectively correlate all variables under different communication scenarios, such as bad weather, traffic congestion, and the presence of buildings and trees. The simulation needs to be optimised for city, urban, and rural areas, which takes into account different vehicular speed and traffic density.

Conflicts of interest

The author declares no conflict of interest.

Author contributions

Mahmoud Iskandarani carried out methodology, software, validation, formal analysis, and writing both the original draft preparation, and review and editing.

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References

[1] B. Cimoli, H. Xing, V. Ho, I. Passchier, G. Kakes, S. Rommel, H. Nijmeijer, and I. T. Monroy, “Practical Challenges in Hybrid Communication Ecosystems Based on ITS-G5 and LTE for CACC and GLOSA”, *Frontiers in Future Transportation*, Vol. 3, No. March, pp. 1–13, 2022.

[2] B. Gould and P. Brown, “Information Design for Vehicle-to-Vehicle Communication”, *arXiv*, pp. 1-13, 2022, DOI: 10.48550/arXiv.2207.06411

[3] R. Halili, M. Weyn, and R. Berkvens, “Comparing Localization Performance of IEEE 802.11p and LTE-V V2I Communications”, *Sensors*, Vol. 21, pp.1-21, No. 2031, 2021.

[4] M. Shan, K. Narula, Y. F. Wong, S. Worrall, M. Khan, P. Alexander, and E. Nebot, “Demonstrations of Cooperative Perception: Safety and Robustness in Connected and Automated Vehicle Operations”, *Sensors*, Vol. 21, No. 200, 2020.

[5] D. Soleymani, M. Gholami, G. D. Galdo, J. Mueckenheim, and A. Thiel, “Open sub - granting radio resources in overlay D2D - based V2V communications”, *EURASIP Journal on Wireless Communications and Networking*, Vol.

1, No. 46, pp. 1-29, 2022.

[6] M. Tahir, P. Leviäkangas, and M. Katz, “Connected Vehicles: V2V and V2I Road Weather and Traffic Communication Using Cellular Technologies”, *Sensors*, Vol. 22, No. 1142, pp. 1–14, 2022.

[7] M. E. Zorkany and A. Yasser, “Vehicle To Vehicle “V2V” Communication: Scope, Importance, Challenges, Research Directions and Future”, *The Open Transportation Journal*, Vol. 14, pp. 86–98, 2020.

[8] F. Arena and G. Pau, “An Overview of Vehicular Communications”, *Future Internet*, Vol. 11, No. 27, 2019.

[9] H. E. Zouka, “An Efficient and Secure Vehicular Networks Based on IoT and Cloud Computing”, *SN Computer Science*, Vol. 3, No. 240, pp. 1–8, 2022.

[10] L. Gallo and J. Harri “Analysis of a S-TDMA Distributed Scheduler for Ad-Hoc Cellular-V2X Communication”, *Ad Hoc Networks*, Vol. 85, No. 15, pp. 160-171, 2019.

[11] Q. Hamarsheh, O. Daoud, M. A. Akaidi, A. Damati, and M. Baniyounis, “Robust Vehicular Communications Using the Fast- Frequency-Hopping-OFDM Technology and the MIMO Spatial Multiplexing”, *International Journal of Communication Networks and Information Security*, Vol. 14, No. 1, pp. 19–25, 2022.

[12] L. Hota, B. Nayak, A. Kumar, G. Ali, P. Han, and J. Chong, “An Analysis on Contemporary MAC Layer Protocols in Vehicular Networks : State-of-the-Art and Future Directions”, *Future Internet*, Vol. 13, No. 287, pp. 1–45, 2021.

[13] A. Ameur, A. Lakas, M. Yagoubi, and O. Oubbati, “Peer-to-peer overlay techniques for vehicular ad hoc networks : Survey and challenges”, *Vehicular Communications*, Vol. 34, No. 100455, pp. 1-20, 2022.

[14] L. Cao, H. Yin, J. Hu, and L. Zhang, “Performance Analysis and Improvement on DSRC Application for V2V Communication”, *arXiv: 2102.07023v1*, pp.1-6, 2021.

[15] G. Wijesiri and J. Haapola, “A Discrete-Time Markov Chain Based Comparison of the MAC Layer Performance of C-V2X Mode 4 and IEEE 802.11p”, *IEEE Transactions on Communications*, Vol. 69, No.4, pp. 2505-2517, 2020.

[16] V. Mannoni1, V. Berg, S. Sesia, and E. Perraud, “A Comparison of the V2X Communication Systems: ITS-G5 and C-V2X”, In: *Proc. of 2019 IEEE 89th Vehicular Technology Conference (VTC2019-Spring)*, Kuala Lumpur, Malaysia, 2019.

[17] Y. Zhang and J. Zhang, “Design and Optimization of Cluster-Based DSRC and C-V2X Hybrid Routing”, *Applied Sciences*, Vol. 12, No. 6782, 2022.

[18] V. Charpentier, N. S. Krijestorac, and J. M. Barja, “Latency-aware C-ITS application for improving the road safety with CAM messages on the Smart Highway testbed.”, In: *Proc of IEEE INFOCOM 2022 - IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS)*, New York, NY, USA, 2022.

[19] V. Nguyen, T. Khanh, X. Pham, G. Lee, and E. Huh, “Performance analysis of adaptive MAC protocol in VANETs considering the potential impact on throughput and transmission delays”, *International Journal of Communication Systems*, Vol. 33, No. 1, pp. 1–17, 2019.

[20] L. Zou, T. Wen, Z. Wang, L. Chen, and C. Roberts, “State Estimation for Communication-Based Train Control Systems With CSMA Protocol”, *IEEE Transaction on Intelligent Transportation Systems*, Vol. 20, No. 3, pp. 843-854, 2018.

[21] X. Chen, S. Leng, S. Mao, and F. Wu, “A Generalized Multi-Stage P-Persistent MAC Protocol for V2V Communications”, In: *Proc of 2018 IEEE 18th International Conference on Communication Technology (ICCT)*, Chongqing, China, 2018.

[22] I. S. In and I. S. In, “Analysis of V2V Communication Performance on Roads and Tunnels Surrounded by Mountains”, In: *Proc of 2022 Thirteenth International Conference on Ubiquitous and Future Networks (ICUFN)*, Barcelona, Spain, 2022.

[23] M. Mokhtari, K. Behrouz, and S. hahfarokhi, “P-persistent massive random access mechanism for machine type communication”, *Telecommunication Systems*, Vol. 78, pp. 169-178, 2021.

[24] Z. Pan, M. Saito, J. Liu, and S. Shimamoto, “P-Persistent Energy-Aware Handover Decisions Employing RF Fingerprint for Adaptive-Sized Heterogeneous Cellular Networks”, *IEEE Access*, Vol. 7, pp. 52929–52944, 2019.

[25] Y. Cui, X. Liu, and D. Xu, “Throughput Optimization of the Improved p-CSMA Protocol in PLC Network”, In: *Proc of 2017 3rd IEEE International Conference on Control Science and Systems Engineering (ICCSSE)*, Beijing, China, 2017.

[26] L. Hu, Y. Xiao, and Z. Dai, “Beacon Transmission Rate Allocation Optimization under Synchronized P-Persistent Repetition

MAC Protocol for Platooning", *Wireless Communications and Mobile Computing*, Vol. 2020, No. 8887134, pp. 1-8, 2020.

[27] Y. Liu, L. Liu, J. Liang, J. Chai, X. Lei, and H. Zhang, "High-Performance Long Range-Based Medium Access Control Layer Protocol", *Electronics*, Vol. 9, No. 1273, pp. 1-16, 2020.

[28] J. Shiraishi, H. Yomo, K. Huang, C. Stefanovi, and P. Popovski "Content-Based Wake-Up for Top-k Query in Wireless Sensor Networks", *IEEE Transactions on Green Communications and Networking*, Vol. 5, No. 1, 2021.

[29] N. T. Hang, N. Trinh, N. Ban, M. Raza, and H. Nguyen, "Delay and Reliability Analysis of p-persistent Carrier Sense Multiple Access for Multi-event Industrial Wireless Sensor Networks", *IEEE Sensors Journal*, Vol. 20, No. 20, pp. 12402–12414, 2020.

[30] Y. Zhang, A. Gong, Y. Lo, J. Li, F. Shu, and W. Wong, "Generalized p-Persistent CSMA for Asynchronous Multiple-Packet Reception", Vol. 67, No. 10, pp. 6966 – 6979, 2019.

[31] M. Dashora and M. Porwal "Random Access Career Sense Protocol : A Comparative Analysis of Non Persistent and 1 Persistent CSMA", *International Journal on Recent and Innovation Trends in Computing and Communication*, Vol. 2, No. 12, pp. 4021–4025, 2014.

[32] V. Gau, J. Hwang, K. Lan, H. Pai, J. Chen, and Y. Chen, "Latency Minimized Probabilistic CSMA / CA", In: *Proc of the 14th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems Miami, USA*, 2011.

[33] M. Hasan, E. Hossain, and D. Niyato, "Random access for machine-to-machine communication in LTE-advanced networks: Issues and approaches", *IEEE communication Magazine*, Vol. 51, No. 6, pp. 86–93, 2013.

[34] Z. Shafiq, R. Abbas, M. H. Zafar, and M. Basheri, "Analysis and Evaluation of Random Access Transmission for UAV-Assisted Vehicular-to-Infrastructure Communications", *IEEE Access*, Vol. 7, pp. 12427–12440, 2019.

[35] J. Zhu, Z. Tao, and C. Lv, "Performance improvement for IEEE 802.15.4 CSMA/CA scheme in large-scale wireless multi-hop sensor networks", *IET Wireless Sensor Systems*, Vol. 3, No. 2, pp. 93–103, 2013.

[36] T. A. Alani and S. A. Aliesawi, "Driverless Cars with Communication System Based On Multiple Access Protocols", *IOP Conference Series: Materials Science and Engineering*, Vol. 1076, pp. 1-17, 2021.

[37] K. Bilstrup, E. Uhlemann, and E. G. Ström, "Medium access control in vehicular networks based on the upcoming IEEE 802.11p standard", In: *Proc of 15th World Congr. Intell. Transp. Syst. ITS Am. Annu. Meet*. 2008.

[38] M. Ma, K. Liu, X. Luo, T. Zhang, and F. Liu, "Review of MAC Protocols for Vehicular Ad Hoc Networks", *Sensors*, Vol.20, No. 6709, 2020.

[39] R. Soua, I. Turcanu, F. Adamsky, D. Fuhrer, and T. Engel, "Multi-Access Edge Computing for Vehicular Networks: A Position Paper", In: *2018 IEEE Globecom Workshops (GC Wkshps)*, Abu Dhabi, United Arab Emirates, 2019.

[40] B. Toghi, M. Saifuddin, H. Mahjoub, M. Mughal, Y. Fallah, J. Rao, and S. Das, "Multiple Access in Cellular V2X: Performance Analysis in Highly Congested Vehicular Networks", In: *Proc. of 2019 IEEE Vehicular Networking Conference (VNC)*, Taipei, Taiwan 2018.

[41] F. Boukhalfa, M. Hadded, P. Muhlethaler, and O. Shagdar, "An analytical model for performance analysis of an active signaling-based TDMA MAC protocol for vehicular networks", In: *Proc. of 2019 IEEE 90th Vehicular Technology Conference (VTC2019-Fall)*, Honolulu, HI, USA, 2019.

[42] M. Hadded, P. Muhlethaler, A. Laouiti, R. Zagrouba, and L. A. Saidane, "TDMA-Based MAC Protocols for Vehicular Ad Hoc Networks: A Survey, Qualitative Analysis, and Open Research Issues", *IEEE Communications Surveys & Tutorials*, Vol. 17, No. 4, pp. 2461–2492, 2015.

[43] Z. Zheng, S. Jiang, R. Feng, L. Ge, and C. Gu, "entropy Survey of Reinforcement-Learning-Based MAC Protocols for Wireless Ad Hoc Networks with a MAC Reference Model", *Entropy*, Vol.25, No.1 2023.

[44] J. Choi, J. Nam, and Y. Cho, "Robust broadcast scheme regardless of vehicle distribution in vehicular ad hoc networks", *EURASIP Journal on Wireless Communications and Networking*, Vol. 2014, No. 133, pp. 1–8, 2014.

[45] R. MacKenzie and T. O'Farrell, "Throughput analysis of a p-persistent CSMA protocol with QoS differentiation for multiple traffic types", In: *Proc. of 2008 IEEE International Conference on Communications*, Beijing, China, 2008.

[46] Y. Zhang, A. Gong, Y. H. Lo, J. Li, F. Shu, and W. Wong, "Generalized p-Persistent CSMA for Asynchronous Multiple-Packet Reception", *IEEE Transactions on Communications*, Vol. 67, No. 10, pp. 6966–6979, 2019.

[47] S. Abukharis and T. O'farrell, "A new adaptive

differentiated p-persistent CSMA protocol that reduces the effect of the transmission errors on the system throughput performance", In: *Proc. of 2011 7th International Wireless Communications and Mobile Computing Conference,* Istanbul, Turkey, 2011.

[48] R. Bruno, M. Conti, and E. Gregori, "Optimal capacity of p-persistent CSMA protocols", *IEEE Communications Letters,* Vol. 7, No. 3, pp. 139–141, 2003.

[49] R. Bruno, M. Conti, and E. Gregori, "Optimization of efficiency and energy consumption in p-persistent CSMA-based wireless LANs", *IEEE Transactions on Mobile Computing,* Vol. 1, No. 1, pp. 10–31, 2002.

[50] H. Zejun, D. Hongwei, B. Liyong, Y. Zhijun, and L. Qianlin, "Analysis of new multi-priority P-CSMA of non-persistent type random multiple access ad hoc network in MAC protocol analysis", *Int. J. Commun. Networks Distrib. Syst.*, Vol. 25, No. 1, pp. 57–77, 2020.