International Journal of
Intelligent Engineering & Systems

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Sinusoidal Regression Modelling of Vehicular Data Communication Employing NP-CSMA

Mahmoud Zaki Iskandarani[1]*

[1]*Faculty of Engineering, Al-Ahliyya Amman University, Jordan*
* Corresponding author's Email: m.iskandarani@ammanu.edu.jo

Abstract: The objective is to investigate effect of slot probability and its effectiveness in vehicular communication. The work carries out MATLAB simulation covering three different levels of slot probability; low, medium, and high. The goal behind such simulation is to uncover the process that leads to high reduction in throughput. The normal explanation for the reduction is high levels of collisions and re-transmission of data through new attempts. However, this work shows that such process can be characterized and controlled as the work shows through sinusoidal regression, the oscillatory behavior caused by collisions, attempts, retransmission, as a function of slot probability. The simulation results, which covers 20 vehicles at various slot probability levels, shows that there is a change in the data traffic-throughput shape function. This is due to the effect of slot probability and reflects on the level of obtained oscillations. The work also discovered an oscillation pattern that infiltrate and affect communication channels at different levels as a function of collisions and data delivery attempts, which is related to slot probability and data traffic. Such oscillatory pattern should be investigated further and the conditions for such pattern should be eliminated, in order to achieve better utilization of communication channel and higher throughput, with lower attempts and less collisions. This is also related to both slot probability and number of available slots. The obtained results in this work showed that at the upper part of the mid slot probability range and all the way to through the high slot probability part, a noticeable oscillatory behaviour is observed, with almost constant values of average data traffic and throughput values. These effects are accompanied by large acceleration and accumulation of collisions. Thus such new approach, and in conjunction with NP-CSMA, can be used at both the design stage of communication channels and vehicular networks, and during operations. This will enable adaptive slot allocation and dynamic transmission of messages, which will result in collisions reduction and better channel utilization.

Keywords: NP-CSMA, Connected vehicles, Network connectivity, Collisions, Throughput, Oscillations, Slot probability.

1. Introduction

The randomness issue is a critical issue for consideration as it is a key factor in collisions. When vehicular nodes transmit data such as basic safety messages (BSMs), there is a probability for collision, which is related to the number of transmitting nodes or stations and slot probability. After a collision, it is required that the contributing parts backoff for a different number of slots, to avoid collision on their next attempt. Controlling collisions and associated randomness with correlated attempts, is essential to avoid saturation and multiplicative collisions and re-transmissions, and the overall process converges, which will increase throughput and communication channel efficiency [1-10].

Researchers discussed communication and authentication protocols concerned with vehicular communication using single and multi-hop approaches with limited number of vehicles due to communication channel characteristics and bandwidth, where machine learning was used to improve communication [1]. This approach is supported by other studies that looked at communication patterns within a vehicular network, in order to improve communication efficiency [2]. These studies are supported by other research work looking at interaction between the multiple connected entities consists of information exchange through the adoption of suitable communication protocols, which should enable efficient data exchange within a vehicular structure [3]. Such works also complimented by more studies regarding increasing efficiency through path prediction, which should enable less data traffic congestion and better channel utilization [4]. Other works concentrated on the effect of using heterogonous networks on communication effectiveness and ability to improve data throughput using different networks [5].

Channel modelling and characterization is a core approach in vehicular communication, which takes into account the structure and communication protocols at the physical layer level using media access control. Researchers discussed modelling of vehicular channels, as prime parameters that need to be optimally defined [6], as wireless signals propagate from the transmitter to the receiver through different routes, each with different time-varying propagation delays, amplitude attenuations, and phase change. Such multipath variables may act constructively or destructively at receiving end. Such wave treatment approach is of considerable importance, with the destructive effect at the receiving end can be due to collisions and phase cancelation. Such modelling and analysis in terms of collisions and waves is not discussed by anyone yet. Other studies with relevance in terms of communication efficiency and vehicular modelling with secure channels and implementation of Dedicated Short Range Communication (DSRC), and with 5G proposals also did not model collisions as destructive propagating waves as proposed in this work [7-10].

Carrier sense multiple access (CSMA) is a much research and applied media access control (MAC) protocols, as it allows multiple users to share a common communication medium [11-20].

Research work concerning vehicle to everything (V2X) communication technology with emphasis on high reliability for safety message exchange in real time within a vehicular communication network, is heavily researched [11]. Such studies concentrated on physical layer representation and communication standards, such as IEEE 802.11p MAC and its protocol performance as a function of packet delivery efficiency, packet arrival rate, and packet size, using simulation and analysis. Such simulations looked at both exponential and deterministic arrival times, with particular attention to hidden terminal problem, which can cause collisions, and performance degradation as a function of such issue. However, none of the works looked at wave modelling and resulting oscillations due to collisions as this work discusses. Other studies considered cross-layer concept with location based simulation and analysis to avoid interference and collisions [12]. Further studies considered MAC, with attention to network density, with many nodes contenting for access to the communication medium. Thus, proper MAC requires to have capacity for V2V exchanges. Such works considered modifications to the existing 802.11p MAC protocol, using intelligent reinforcement learning, focused on collision levels reduction and channel bandwidth preservation. The works is carried out using simulation in order to optimize vehicular networks performance [13]. Such studies are supported by contention window optimization through simulation, which will enhance performance as a function of vehicular density, and carried out through modifications to carrier sensing multiple access with collision avoidance protocol [14].

Further work by researchers looked at collisions, at the physical layer level with contention avoidance, and used mobility-triggered message generation patterns, and modelled the arrival process at the receiving end using discrete markovian arrival process [17]. However, no studies modelled the communication pattern using wave-like approach as proposed in this work.

When using non-persistent carrier-sense multiple access (NP-CSMA) protocol, each node will sense the channel status before transmitting. If the node finds the communication channel state is idle, the data is sent immediately; otherwise, the data is delayed for an amount of time before sensing the channel again. There is always a possibility of collision, when two or more data frames or packets are simultaneously sent. Thus resolving contention among nodes is a critical process using MAC protocol, with exponential backoff algorithm being used conventionally to resolve collisions, even though it is stability is in question when it comes to infinite number of nodes [21-26].

Non-persistent CSMA is used by researchers in a discrete manner with multi-channel mechanism and binary tree with conflict resolution approach [21]. This method proved through modelling and analysis that fairer resource allocation is achieved with better communication channel efficiency. Other works used multichannel non-persistent CSMA MAC schemes with reinforcement learning and state-action-reward-state-action (SARSA) learning. This covered radio based communicating networks, in order to optimize channel access and reduce collisions [22]. Others discussed a three-clock non-persistent CSMA, which is based on variable collision length, aimed at improving system throughput [23]. The system used throughput, collision rate as main parameters for such an adaptive approach. Others combined passion based packet size and Semi-Markov processes in a slotted NP-CSMA in order to achieve better channel utilization [24]. Such work is complimented by research using NP-CSMA and time division multiple access (TDMA) [25], with supportive work on predicting and estimating upper bounds using NP-CSMA to control collisions at high network density [26].

All previous mentioned studies did not model communication interaction using wave like functions and effect of contention with NP-CSMA at affecting shape function and causing oscillations as this work proposes.

In the carrier-sense multiple access (CSMA) version of the medium access control (MAC) protocol, a node verifies that no other traffic is present before broadcasting on a shared transmission media. According to CSMA, a transmitter first uses a carrier-sense technique to see if another transmission is already underway. Before attempting to broadcast, it determines whether a carrier signal from another node is present. In the event that a carrier is found, the node waits for the previous transmission to end before beginning a new one. With CSMA, many nodes can send and receive data over the same medium sequentially.

Several CSMA variations use different techniques to decide when to start transmitting onto the shared medium. The aggressiveness or persistence of these algorithms in starting transmission is a key distinction. A more aggressive algorithm might begin sending more quickly and utilize more of the bandwidth that is available on the media. This typically entails a greater risk of transmitter collisions [27-29].

Non-aggressive transmission algorithm is non-persistent CSMA. While getting ready to send data, the transmitting node checks to see if the transmission medium is free or occupied. If not moving, it immediately communicates. If the channel is busy, it jumps right to the last random waiting step of the 1-persistent CSMA before resuming the complete logic cycle. The name comes from avoiding repeatedly monitoring the busy channel while attempting to transmit a message. In comparison to 1-persistent, this approach causes a longer initial delay but reduces the risk of collision and boosts medium throughput overall [30-31].

Throughput maximization using reinforcement learning and NP-CSMA is carried out by researchers to support non-aggressive transmission, which would result in a better channel utilization and lower collisions [27]. Such work is further developed to include reselection of lock heads to enable minimization of aggressive transmission [28]. Also, complementing methods such as multi-priority is used to support NP-CSMA non-aggressive approach [29], with routing algorithms modified to allow for load aware routing, which adapts to NP-CSMA technique [30]. However, no study simulated and modelled NP-CSMA and communication channel throughput using wave-like function related to slot probability as proposed in this work.

Studies showed that if the arrival rate of a system is markedly small, the exponential backoff would be sufficiently stable, with throughput not affected by the issue of nodes with throughput stability a function of exponential backoff [32-34].

Vehicular ad-hoc networks (VANETs) operate primarily on broadcast transmissions, with exchanged data is used by vehicles within a certain radius. There is always a possibility that transmitted signals might interfere with each other, when two or more vehicles (stations) attempt to transmit over a shared channel. This will lead to contention, specifically as the MAC specification of IEEE 802.11 and IEEE 802.11p has no requirement for acknowledgements (ACKs) packets to be sent based on receiving broad cast message such as the basic safety message (BSM), thus eliminating ACKs storm [35-39].

Exponential backoff scheduling is used with NP-CSMA by many researchers [33]. Studies included analysis of the throughput and delay distribution, with focus on stable regions and bounded mean delay of Retransmission. More advanced studies proposed collaborative NP-CSMA in order to eliminate collision altogether, and avoid using TDMA [34]. Such studies might not be very fruitful, especially in emergency situations, whereby vehicles need to transmit and have priority. Recent studies proposed to use selected data packets to propagate the reservation of data resources and apply scheduled assignment technique [37]. The authors claim that this approach will provide better communication among neighbour vehicles in terms of resource reservation and will reduce data collisions. This is carried out using simulation.

None of the mentioned approaches simulated and modelled communication channel behaviour and transmission slots in terms of oscillatory patterns as proposed in this work.

Vehicle-to-Vehicle (V2V) Communication continues to develop, and supports, more efficient transportation with added safety, using wireless connection among vehicles. This technology depends on the specifications and functionality of MAC layers, governed by the general IEEE802.11, and the specific IEEE802.11p protocols stack [40-42].

V2V networks forms VANETs and as broadcast networks, they are more susceptible to contention, specifically as vehicular density increases, which increase the rate of collision.

VANETs exchange data with other vehicles in an area of interest. The broadcasted data packets are not addressed to a particular MAC, in order for all vehicles within the interested area interact. Thus acknowledgements are not necessary and this makes communication without authentication is more appropriate for the vehicular environment. Exchanged signals will interfere with each other in many cases, as more than one station will attempt to send data.

This work investigates through simulation the effectiveness of NP-CSMA for vehicular medium access control (MAC), which is affected by slot probability and re-transmissions of data due to collisions, and further complicated by vehicular movements. In this paper a detailed characterization and analysis of the efficiency of vehicular connectivity using NP-Persistent is investigated, with new approach through wave behaviour modelling of the effect of slot probability on channel communication, by observation of oscillatory behaviour.

The contribution of this work is:

1. Simulation of vehicular communication using NP-CSMA under different slot probability levels.
2. Establishing effect of shape function changes for throughput-data traffic figures as it affected by probability level.
3. Detailed mathematical modelling of throughput, data traffic, buffered frames as a function of slot probability.
4. Modelling of effect of collisions on channel utilization through changes in throughput, buffered frames.
5. Introducing the concept of Oscillatory pattern recognition, as a function of slot probability. This will enable adaptive and dynamic communication channel management.

2. Methodology

The effectiveness and efficiency of vehicle wireless communication is crucial to managing traffic flow and maintaining safety. Vehicles will engage with one other while driving and using decentralized Vehicle to Vehicle communication (V2V), which strains communication networks.

This work investigates the limits of the NP-CSMA random multiple access protocol, which could be used in vehicular networks. It is known that the dynamic performance when a slot is randomly selected is affected by complex balancing conditions. If the competing nodes transmits heavily, the probability of collision significantly increases, but if the transmission rate is low with low slot probability, and there are many available slots, this will leave most slots unused, and thus throughput and performance drops.

Thus, it is essential that an optimum probability value(s) correlated to throughput is found with any affecting conditions investigated.

The approach in this work operates on the principle of analysing the simulated results obtained for three ranges of slot probability:

1. 0.001-0.009
2. 0.01-0.09
3. 0.1-0.9

The simulated results will be analysed to enable characterization of the communication effectiveness under different slot probability, and establishing a pattern of communication channel behavior as a function of increasing vehicular interaction, resulting from increasing slot probabilities and affecting attempts and collisions. Table 1 shows the used acronyms and their definition.

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

3. Results and Discussion

3.1 Low slot probability

Figs. 1 to 5 present the simulation results for an incrementing number of vehicles (communicating nodes) as a function of increasing slot probability in the low range of 0.001 to 0.009. The Figures show a change in the shape function as the probability in the low range increases. This is due to more probability of data exchange using the communication channel, which affects both attempts and collisions. The interaction affects data traffic-throughput response curve and shape function.

Fig. 6 shows the relationship P and G_{avg}, which can be described using polynomial, with approximation as shown in Eq. (1).

Received: March 30, 2023. Revised: April 16, 2023.

Table 1. Nomenclature

Symbols/ Acronyms	**Meaning**
Vn	Nodes Number: Number of vehicles that generate packets.
P	Slot probability: probability that a specific node or station has a data ready to be transmitted at a particular time slot.
S	Throughput of the NP-CSMA random access protocol.
T	Mean delay (in slots) for a successfully transmitted and acknowledged packet.
G	Normalized available traffic, with retransmissions included.
Buf_{total}	Total buffered number of frames.
R_s	Ratio of successfully delivered frames to number of attempts.
R_c	Ratio of number of collisions to number of attempts.
V_n	Nodes Number: Number of vehicles that generate packets.
G_{avg}	Average normalized available traffic, with retransmissions included.
η, κ	Optimizing parameters relating average data traffic to low slot probability.
S_{avg}	Average throughput of the NP- Carrier Sensing Multiple Access protocol.
λ, ε	Optimizing parameters relating average throughput to low slot probability.
α, β	Optimizing parameters relating average throughput to average data traffic as a function of low slot probability.
γ, θ	Optimizing parameters relating average data traffic to total buffered number of frames as a function of low slot probability.
ϕ, ψ	Optimizing parameters relating average data traffic to mid slot probability.
χ , ω	Optimizing parameters relating average throughput to mid slot probability.
ν, ϑ	Optimizing parameters relating average throughput to average data traffic as a function of mid slot probability.
σ, ξ	Optimizing parameters relating average data traffic to total buffered number of frames as a function of mid slot probability.
Φ, Θ, δ, Ω	Optimizing parameters relating average data traffic, average throughput to high slot probability.
Γ, ζ, Ψ, Κ	Optimizing parameters relating average data traffic, average throughput to total buffered number of frames as a function of high slot probability.
A, B, M, N	Optimizing parameters relating ratio of successfully delivered frames to number of attempts, and ratio of number of collisions to number of attempts to low, mid, and high slot probability levels and associated average data traffic.

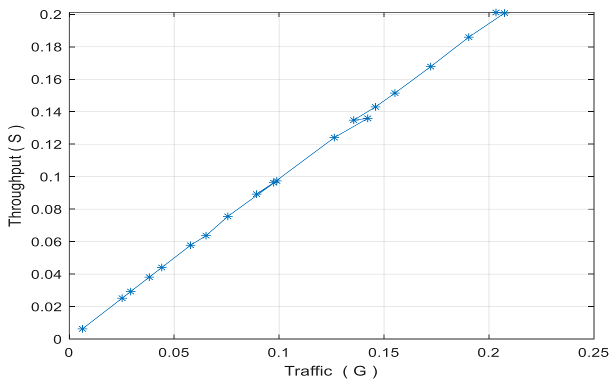

Figure. 1 Relationship between throughput and data traffic for P=0.001

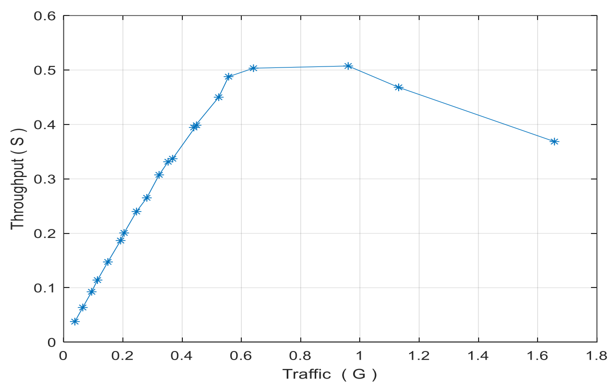

Figure. 2 Relationship between throughput and data traffic for P=0.003

 DOI: 10.22266/ijies2023.0630.50

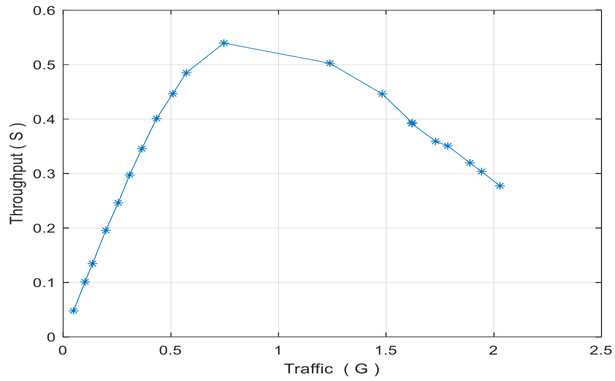

Figure. 3 Relationship between throughput and data traffic for P=0.005

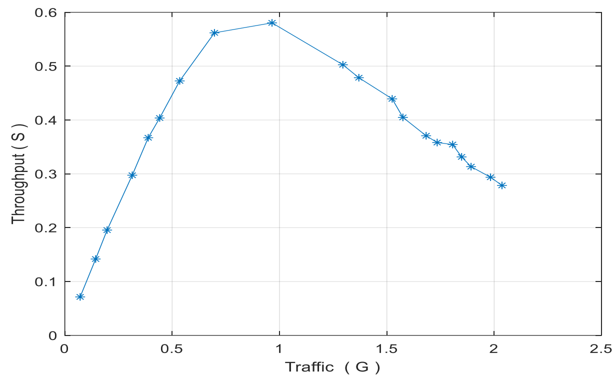

Figure. 4 Relationship between throughput and data traffic for P=0.007.

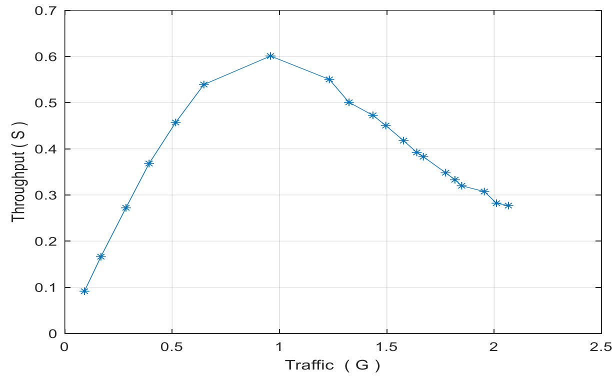

Figure. 5 Relationship between throughput and data traffic for P=0.009

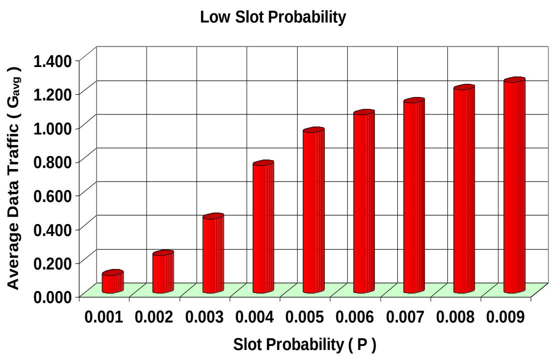

Figure. 6 Relationship between slot probability and average traffic

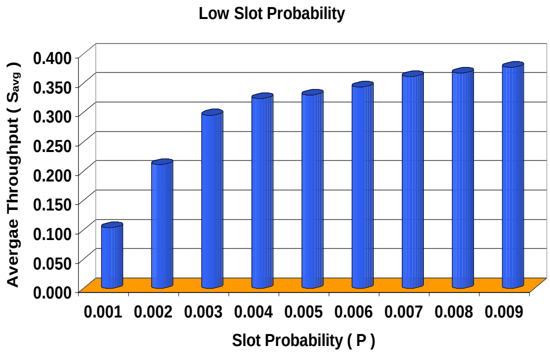

Figure. 7 Relationship between slot probability and throughput

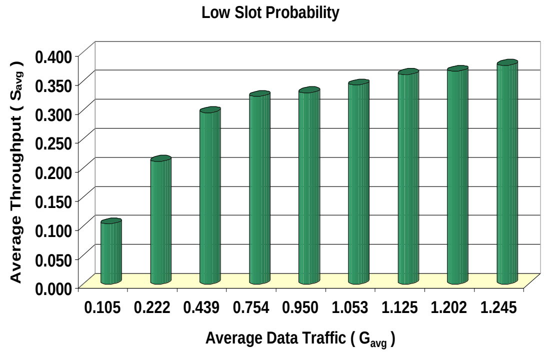

Figure. 8 Relationship between G_{avg} and S_{avg} for low probability range

$$G_{avg} = \eta log_e(P) + \kappa \quad (1)$$

$$Where;\ \eta \leq 0.6, \kappa \geq 4$$

Fig. 7 shows the relationship P and S_{avg}, which can be described using polynomial expression, with approximation as shown in Eq. (2).

$$S_{avg} = \lambda log_e(P) + \varepsilon \quad (2)$$

$$Where;\ \lambda \geq 0.1, \varepsilon \geq 1$$

Fig. 8 shows the relationship G_{avg} and S_{avg}, which can be described using polynomial function, with approximation as shown in Eq. (3).

$$S_{avg} = \alpha log_e\left(G_{avg}\right) + \beta \quad (3)$$

$$\text{Where};\ \alpha \geq 0.1, \beta \leq 0.35$$

Fig. 9 shows the relationship G_{avg} and Buf_{total}, which can be described using polynomial function, with approximation as shown in Eq. (4).

$$G_{avg} = \gamma Buf_{total}{}^{\theta} \quad (4)$$

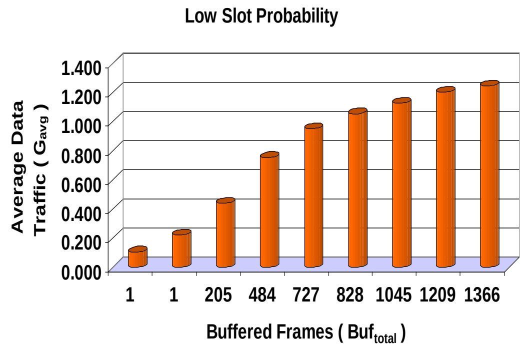

Figure. 9 Relationship between G_{avg} and Buf_{total}

Where; $\gamma \geq 0.14, \theta \geq 0.28$

From Eqs. (1), and (4), Eq. (5) is obtained.

$$Buf_{total} = \left|\frac{\eta log_e(P)+\kappa}{\gamma}\right|^{\theta^{-1}} \quad (5)$$

As realized in Figs. 10 to 13, there is no apparent oscillation in the plots. The response curves described by natural logarithmic equations, except for the relationship that describes buffered frames, it is power law equivalent. This is the first parameter that affects connectivity effectiveness and contributes to lowering the throughput of the communication channel if not controlled effectively. The buffered frames function is affected by both data traffic and slot probability, thus, controlling slot probability, will control data traffic and subsequently, will affect buffered frames. This will also have an effect on the level of collisions and attempts.

3.2 Mid slot probability

Figs. 10 to 14 present the simulation results for an incrementing number of vehicles (transmitting nodes) as a function of increasing transmission probability in the medium range of 0.01 to 0.9. This second slot probability interval, shows continuous shape function change with increased data traffic as a result of higher slot probability.

The change in shape function is also a result of increase in collisions and attempts to deliver data over the communication channel. This is clear, as there is no more start from low throughput values to high, then drops gradually to lower values. The interval ends with start from high values of throughput and gradually drops. This is due to buffering of large number of frames.

Fig. 15 shows the relationship P and G_{avg}, which can be described using fourth order polynomial, with approximation as shown in Eq. (6).

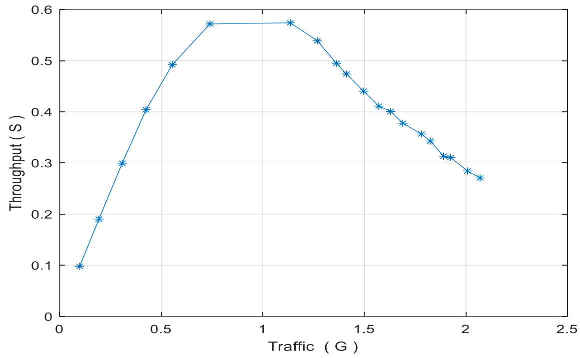

Figure. 10 Relationship between throughput and data traffic for P=0.01.

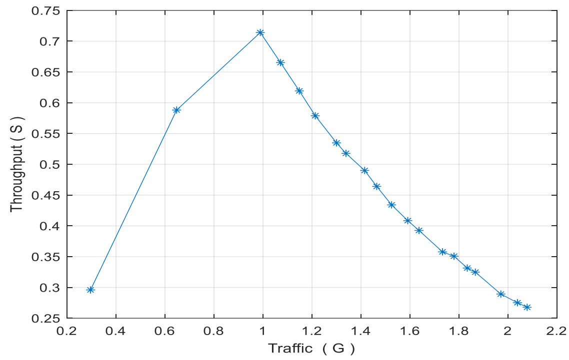

Figure. 11 Relationship between throughput and data traffic for P=0.03

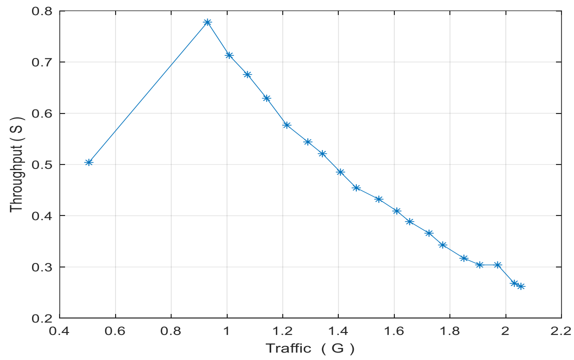

Figure. 12 Relationship between throughput and data traffic for P=0.05

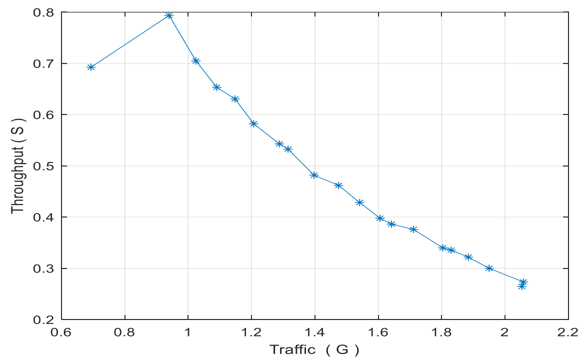

Figure. 13 Relationship between throughput and data traffic for P=0.07

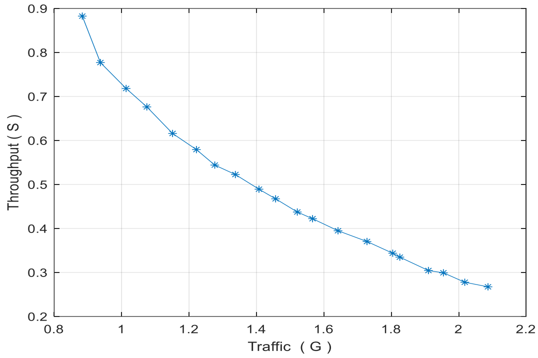

Figure. 14. Relationship between throughput and data traffic for P=0.09

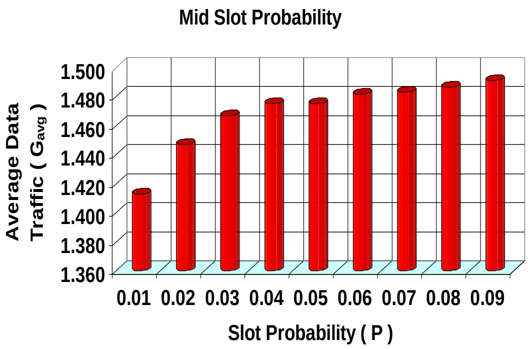

Figure. 15 Relationship between slot probability and average data traffic

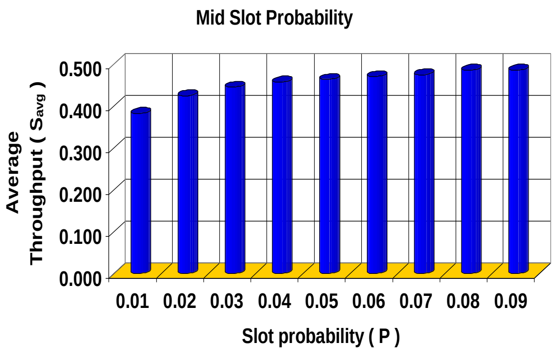

Figure. 16 Relationship between slot probability and average throughput

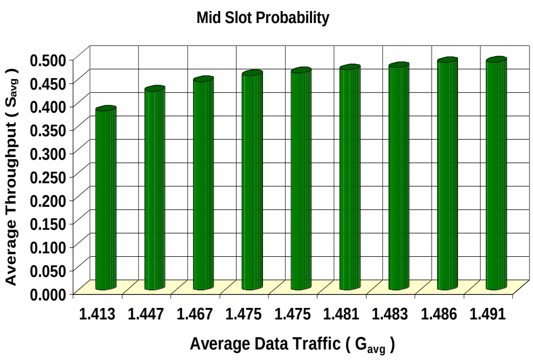

Figure. 17 Relationship between G_{avg} and S_{avg} for mid slot probability

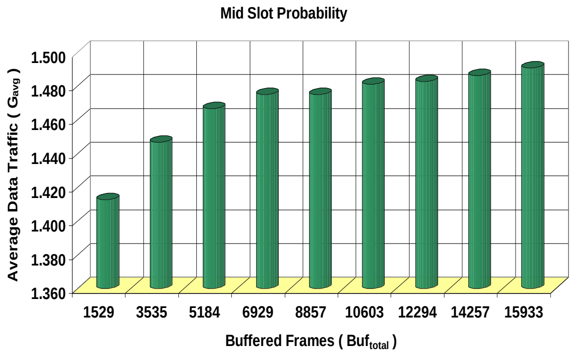

Figure. 18 Relationship between P and Buf_{total}

$$G_{avg} = \phi P^{\psi} \tag{6}$$

Where; $\phi \leq 1.6, \psi \geq 0.02$

Fig. 16 shows the relationship P and S_{avg}, with approximation as shown in Eq. (7).

$$S_{avg} = \chi P^{\omega} \tag{7}$$

Where; $\chi \leq 0.6, \omega \geq 0.1$

Fig. 17 shows the relationship S_{avg} and G_{avg}, with approximation as shown in Eq. (8).

$$S_{avg} = \nu {G_{avg}}^{\vartheta} \tag{8}$$

Where; $\nu \leq 0.08, \vartheta \geq 4.5$

Fig. 18 shows the relationship Buf_{total} and G_{avg}, with approximation as shown in Eq. (9).

$$G_{avg} = \sigma {Buf_{total}}^{\xi} \tag{9}$$

Where; $\sigma \geq 1.2, \xi \geq 0.02$

From Eqs. (6), and (9), Eq. (10) is produced.

$$Buf_{total} = \left(\frac{\phi P^{\psi}}{\sigma}\right)^{\xi^{-1}} \tag{10}$$

It is noticeable in Figs. 23 to 26, the existence of small oscillatory pattern. The pattern is not affecting the overall results or approximation, thus it can be ignored at this stage. However, it is an indication, that instability in the communication channel system is occurring, and starting at the higher levels of this mid-range of slot probability (P=0.01-0.09).

In addition, there is a change in the overall approximated function relating data traffic to slot probability, and to throughput, with power function

Received: March 30, 2023. Revised: April 16, 2023.

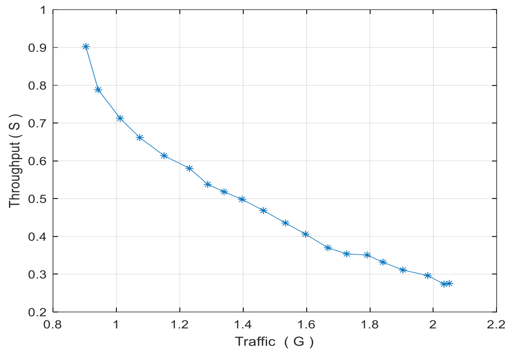

Figure. 19 Relationship between throughput and data traffic for P=0.1

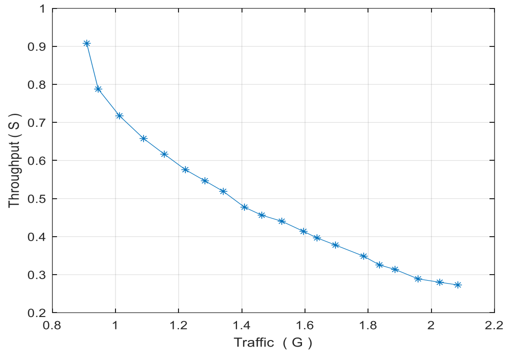

Figure. 20 Relationship between throughput and data traffic for P=0.3

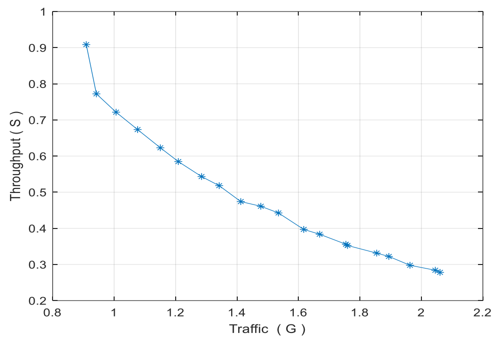

Figure. 21 Relationship between throughput and data traffic for P=0.5

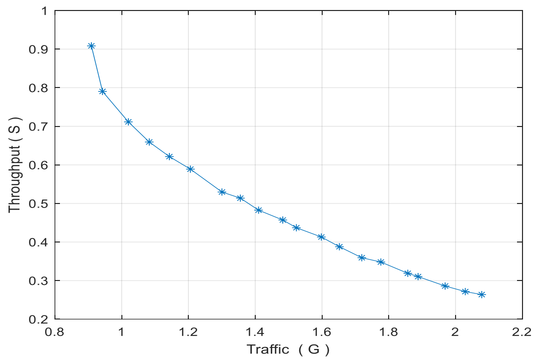

Figure. 22 Relationship between throughput and data traffic for P=0.7

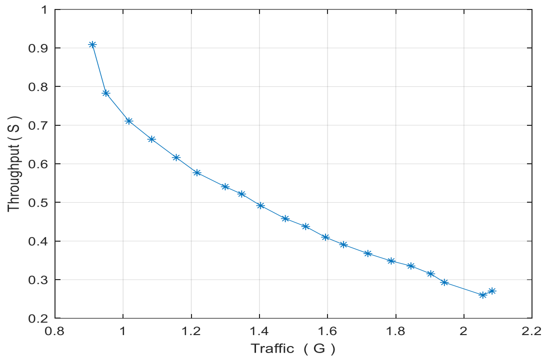

Figure. 23 Relationship between throughput and data traffic for P=0.9

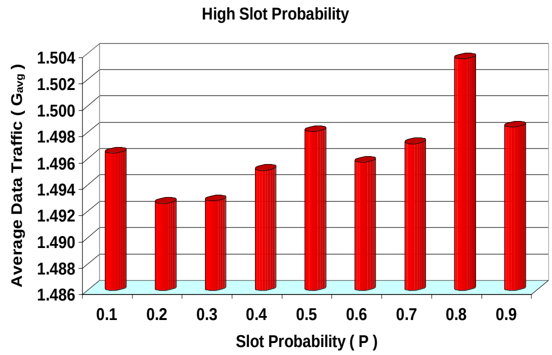

Figure. 24 Relationship between slot probability and average data traffic

also relating both throughput and buffered frames to slot probability. The change in the overall function to power, is further supports the instability hypothesis.

3.3 High slot probability

Figs. 19 to 23 present the simulation results for an incrementing number of vehicles (communicating nodes) as a function of increasing transmission probability in the high range of 0.1 to 0.9.

The shape function in Figures almost stays the same regardless of the slot probability within the range (P=0.1-0.9). This is indicative that a threshold level of buffering, and collisions is reached with equivalent shape functions across the slot probability range. This forms a foundation for oscillatory behaviour in a similar manner to resonance.

Fig. 24 shows the relationship P and G_{avg}. The relationship displays an oscillatory condition, whereby with sinusoidal regression approximation as shown in Eq. (11). This behaviour is consistent with the unchanged shape function across the slot probability range.

$$G_{avg} = \Phi\, sin(\Theta P - \delta) + \Omega \qquad (11)$$

Where; $\Phi \geq 0.01, \Theta \geq 64, \delta \geq 1.5, \Omega \geq 1.5$

Received: March 30, 2023. Revised: April 16, 2023.

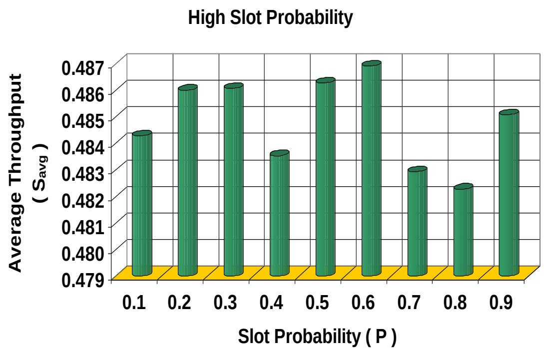

Figure. 25 Relationship between slot probability and average throughput

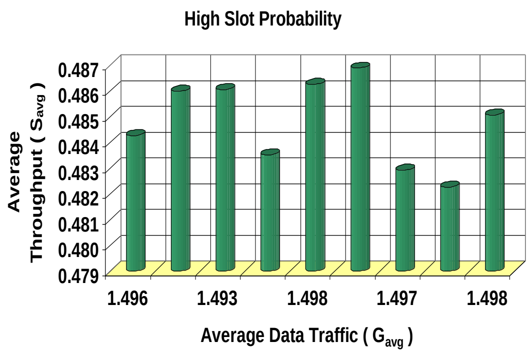

Figure. 26 Relationship between G_{avg} and S_{avg} for high slot probability

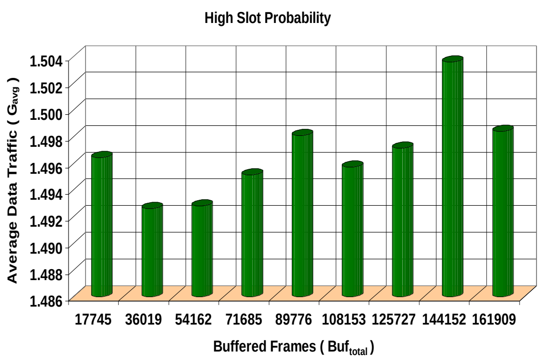

Figure. 27 Relationship between G_{avg} and Buf_{total} for high slot probability

Fig. 25 shows the relationship S_{avg} and P. The relationship displays an oscillatory condition, whereby with sinusoidal regression approximation as shown in Eq. (12).

$$S_{avg} = \Phi \sin(\Theta P - \delta) + \Omega \tag{12}$$

Where; $\Phi \leq 0.01, \Theta \geq 64, \delta \geq 1, \Omega \leq 0.5$

Fig. 26 shows the relationship S_{avg} and G_{avg}. The relationship displays an oscillatory condition, whereby with sinusoidal regression approximation as shown in Eq. (13).

Table 2. Relationship between slot probability and average data traffic

P-Low	G_{avg}-Low	P-Mid	G_{avg}-Mid	P-High	G_{avg}-High (Oscillation)
0.001	0.105	0.01	1.413	0.1	1.496
0.002	0.222	0.02	1.447	0.2	1.493
0.003	0.439	0.03	1.467	0.3	1.493
0.004	0.754	0.04	1.475	0.4	1.495
0.005	0.950	0.05	1.475	0.5	1.498
0.006	1.053	0.06	1.481	0.6	1.496
0.007	1.125	0.07	1.483	0.7	1.497
0.008	1.202	0.08	1.486	0.8	1.504
0.009	1.245	0.09	1.491	0.9	1.498

$$S_{avg} = \Phi \sin\left(\Theta G_{avg} - \delta\right) + \Omega \tag{13}$$

Where; $\Phi \geq 0.009, \Theta \geq 64, \delta \geq 0.3, \Omega \leq 0.5$

Fig. 27 shows the relationship Buf_{total} and G_{avg}. The relationship displays an oscillatory condition, whereby with sinusoidal regression approximation as shown in Eq. (14).

$$G_{avg} = \Gamma \sin(\zeta Buf_{total} + \Psi) + K \tag{14}$$

Where; $\Gamma \leq 0.005, \zeta \geq 0.10, \Psi \geq 0.8, K \leq 1.5$

From Eqs. (11), and (14), Eq. (15) is produced.

$$Buf_{total} = \left(\sin^{-1}\left(\frac{\Phi \sin(\Theta P - \delta) + \Omega - K}{\Gamma}\right) - \Psi\right)\zeta^{-1} \tag{15}$$

The clear difference between high slot probability and both medium and low slot probability values is evident as no oscillations apparent over the low slot probability range, with small oscillatory pattern in the mid-range and now clear oscillatory pattern with fixed shape function in the high-range of slot probability.

Tables 2 and 3 show comparison of G_{avg} and S_{avg} values as a function of slot probability. From the Tables, it is shown that at mid and high probability values, and specifically at high probability values, the values of data traffic and throughput change in little tiny steps with small increments. This is consistent with the shape function change and oscillations, which start at the high end of the mid-range of slot probability and continues throughout the high range, resulting in oscillations.

Table 4 shows a comparison between buffered frames for all ranges of slot probability. The Table clearly show the huge increase in buffered frames as high level slot probability range is reached.

Received: March 30, 2023. Revised: April 16, 2023.

Table 3. Relationship between slot probability and average throughput

P-Low	S_{avg}-Low	P-Mid	S_{avg}-Mid	P-High	S_{avg}-High (Oscillation)
0.001	0.103	0.01	0.382	0.1	0.484
0.002	0.211	0.02	0.425	0.2	0.486
0.003	0.295	0.03	0.445	0.3	0.486
0.004	0.323	0.04	0.458	0.4	0.484
0.005	0.329	0.05	0.464	0.5	0.486
0.006	0.343	0.06	0.470	0.6	0.487
0.007	0.361	0.07	0.475	0.7	0.483
0.008	0.366	0.08	0.486	0.8	0.482
0.009	0.377	0.09	0.486	0.9	0.485

Table 4. Relationship between slot probability and buffered frames

P-Low	Buf_{total}-Low	P-Mid	Buf_{total}-Mid	P-High	Buf_{total}-High
0.001	1	0.01	1529	0.1	17745
0.002	1	0.02	3535	0.2	36019
0.003	205	0.03	5184	0.3	54162
0.004	484	0.04	6929	0.4	71685
0.005	727	0.05	8857	0.5	89776
0.006	828	0.06	10603	0.6	108153
0.007	1045	0.07	12294	0.7	125727
0.008	1209	0.08	14257	0.8	144152
0.009	1366	0.09	15933	0.9	161909

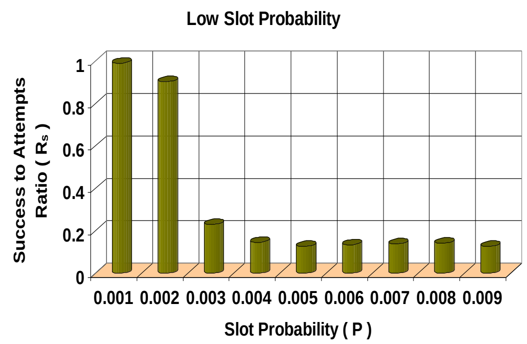

Figure. 28 Relationship between R_s and P for low slot probability

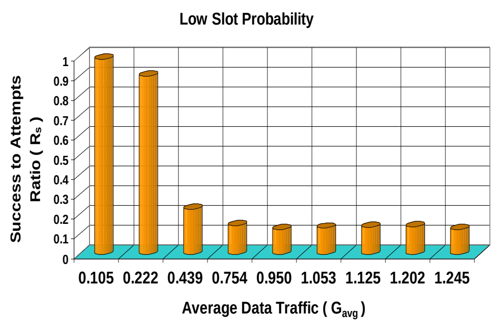

Figure. 29 Relationship between R_s and G_{avg} for low slot probability.

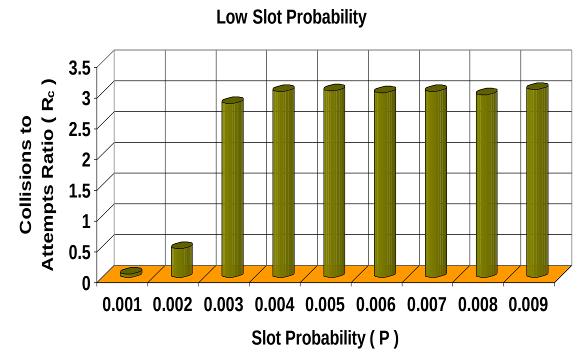

Figure. 30 Relationship between R_c and P for low slot probability

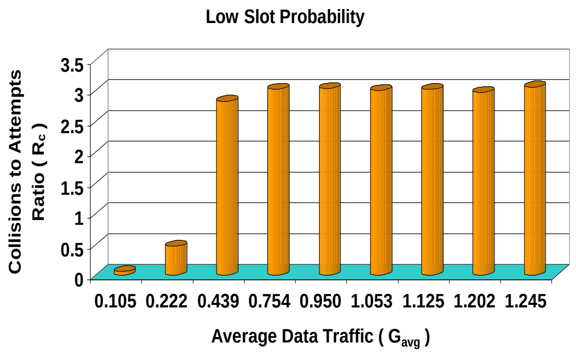

Figure. 31 Relationship between R_c and G_{avg} for low slot probability

Figs. 28 and 29 show the relationship between R_s and P and R_s and G_{avg}. As the Figures show, as slot probability and data traffic increases, the ratio between successfully delivered frames and attempts, decreases. This is due to the increase in collisions and more generated data frames per slot. No oscillatory effect is present.

Figs. 30 to 31 show effect of increasing both G_{avg} and P on the ratio of collisions to attempts. The Figures show an increase in Rc as a function of increasing G_{avg} and P. This is due to increase in slot probability resulting in an increase in collisions due to more data traffic.

Figs. 32 and 33 show the relationship between R_s and P and R_s and G_{avg} for mid-range slot probability. As the Figures show, clear oscillation occurs as a function of increasing slot probability and data traffic. This occurs as slot probability and data traffic increases. This is presented in the sinusoidal regression in Eqs. (16) and (17). This oscillatory effect appeared as a minor pattern previously and is a function of buffering and re-transmission of frames as a result of collisions.

$$R_{s(mid)} = A\,sin(BP + M) + N \qquad (16)$$

Where; $A \leq 0.015, B \geq 640, M \leq 1.7, N \geq 0.1$

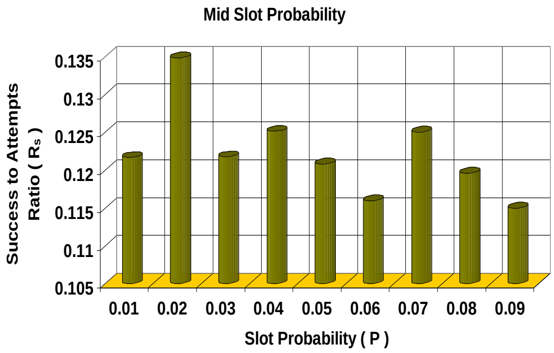

Figure. 32 Relationship between R_s and P for mid slot probability

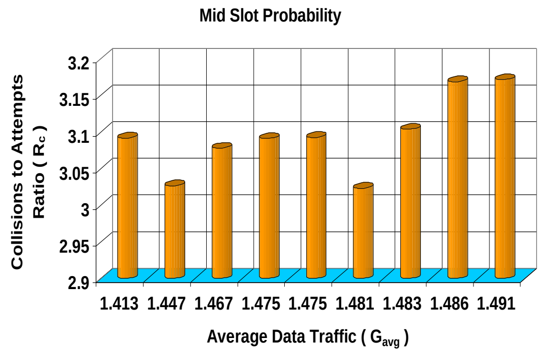

Figure. 35 Relationship between R_c and G_{avg} for mid slot probability

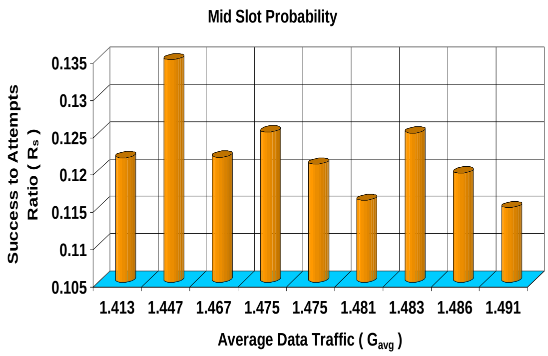

Figure. 33 Relationship between R_s and G_{avg} for mid slot probability

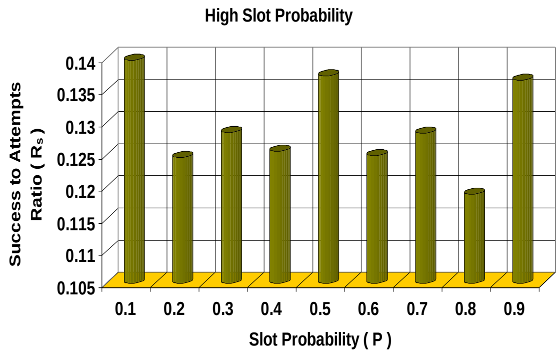

Figure. 36 Relationship between R_s and P for high slot probability

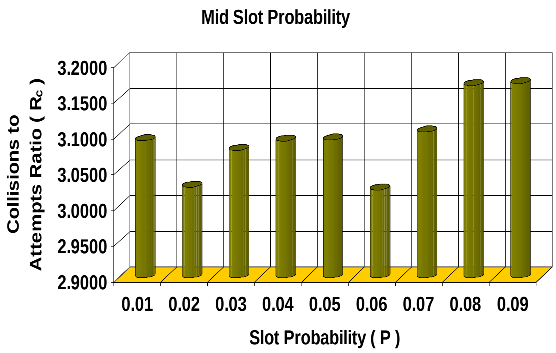

Figure. 34 Relationship between R_s and P for mid slot probability

$$R_{s(mid)} = A\, sin\left(BG_{avg} + M\right) + N \qquad (17)$$

Where; $A \geq 0.008, B \leq 700, M \leq 2.5, N \geq 0.1$

Figs. 34 and 35 show the relationship between R_c and P and R_c and G_{avg} for mid slot probability. It is clear the oscillatory pattern in both plots, which is described by sinusoidal regression in Eqs. (18) and (19). Collisions and attempts are a main cause for tis oscillatory behaviour, even though for the mid-range slot probability, it only shows as a minor pattern when analysing general characteristics.

$$R_{c(mid)} = A\, sin(BP - M) + N \qquad (18)$$

Where; $A \geq 0.13, B \leq 655, M \leq 2.5, N \geq 3.1$

$$R_{c(mid)} = A\, sin\left(BG_{avg} + M\right) + N \qquad (19)$$

Where; $A \leq 0.0.07, B \leq 767, M \geq 1, N \geq 3.0$

Figs. 36 and 37 show the relationship between R_s and P and R_s and G_{avg} for high-range slot probability. As the Figures show, clear oscillation occurs as a function of increasing slot probability and data traffic. This is consistent with main characteristics presented in Figs. 24 to 27. This is related to the unchanging shape function across the high-range, that's why it appeared through both the main characteristics and the ratios presented in Figs. 36 and 37. Also, as the shape function changes for the mid-range slot probability, the minor oscillations only appeared when the ratio plots are presented, as previously discussed. The sinusoidal regression is presented in Eqs. (20) and (21).

$$R_{s(high)} = A\, sin(BP + M) + N \qquad (20)$$

Where; $A \geq 0.006, B \geq 75, M \geq 1.2, N \leq 0.13$

Received: March 30, 2023. Revised: April 16, 2023.

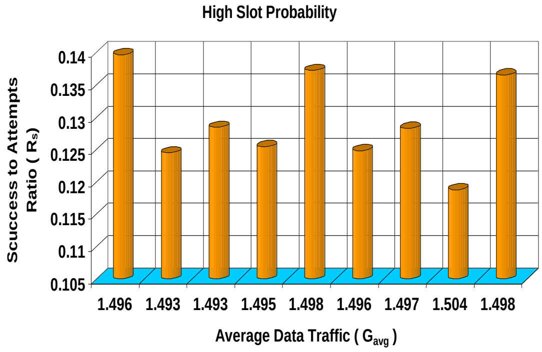

Figure. 37 Relationship between R_s and G_{avg} for high slot probability

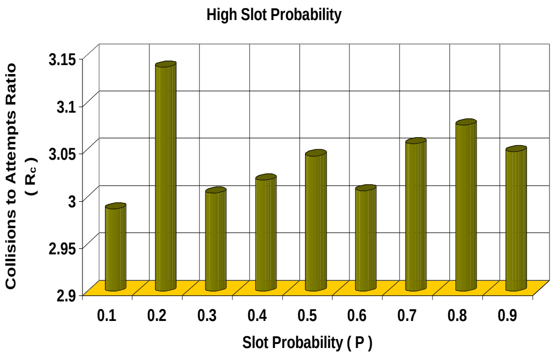

Figure. 38 Relationship between R_c and P for high slot probability

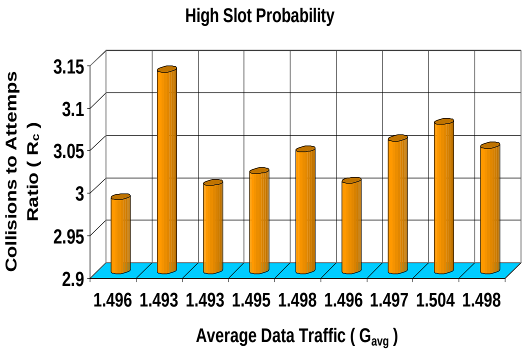

Figure. 39 Relationship between R_c and G_{avg} for high slot probability

$$R_{s(high)} = A\,sin\big(BG_{avg} + M\big) + N \qquad (21)$$

Where; $A \geq 0.006, B \geq 6900, M \leq 0.05, N \leq 0.13$

Figs. 38 and 39 show the relationship between R_c and P and R_c and G_{avg} for high slot probability. It is clear the oscillatory pattern in both plots, which is described by sinusoidal regression in Eqs. (22) and (23).

$$R_{c(high)} = A\,sin(BP + M) + N \qquad (22)$$

Where; $\mathrm{A} \geq 0.55, B \geq 31, M \geq 3, N \geq 3$

$$R_{c(high)} = A\,sin\big(BG_{avg} - M\big) + N \qquad (23)$$

Where; $A \geq 0.06, B \leq 6830, M \leq 2, N \geq 3$

Figs. 38 and 39 show the relationship between R_c and P and R_c and G_{avg} for high slot probability. It is clear the oscillatory pattern in both plots, which is described by sinusoidal regression in Eqs. (22) and (23).

It is clear that there is a matching pattern between slot probability and data traffic, which indicates that the two parameters are closely related and one affects the shape function of the other.

The effectiveness of using NP-CSMA, could be controlled through network management of the oscillatory behavior and patterns in the communication channels with reduction in attempts and to avoid collision increase. Thus, there is a need not to reach a fixed shape function over any range of slot probability, and to avoid saturation.

4. Conclusions

The work investigated through simulation effect of slot probability on effective data transfer in inter-vehicular communication. The work through MATLAB simulation and sinusoidal regression analysis, showed and evidence of oscillation, which is related mainly to high slot probability values and affected by attempts and collisions. The detailed simulations, with mathematical modelling resulted in the following:

1. A logarithmic relationship for G_{avg} and slot probability, and between S_{avg} and G_{avg}, at low probability levels. This is an expected mathematical model.
2. A power relationship between G_{avg}, and slot probability, and between G_{avg} and S_{avg} at mid slot probability. This marks the beginning of a change in the communication shape function.
3. An oscillatory sinusoidal behaviour is realized at high slot probability with sinusoidal relationship between G_{avg} and P. Such pattern change is accompanied by multiplicative collision levels. Thus throughput and data traffic are capped and the communication channel is overloaded.

The paper showed that such oscillatory behaviour should be further analysed and could be controlled to increase throughput and data communication effectiveness, with better communication channel utilization. This can be achieved through optimization of slot probability and number of available slots to avoid multiplicative attempts and collisions.

The work also showed that a constant shape function is indicative of oscillatory behaviour, which should be further investigated.

Overall, the simulation and analysis proved to be successful in pointing main problems with, with the new method supporting more effective use.

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.

Acknowledgments

The simulation software is based on an original version designed by An-Che Teng.

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