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Effect of Waiting Time and Number of Slots on Vehicular Networking Employing Slotted ALOHA Protocol

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Abstract: This work investigates through simulation effect of waiting time and number of slots on the effectiveness of using Slotted ALOHA in vehicular connectivity as a random access technique. The objective is to reach optimum level of throughput under the vehicular dynamic environment. The presented work proposes to concentrate on waiting time as a controlling parameter that can be used in an adaptive manner to enable throughput optimization in response to changing vehicular density. The work proved through MATLAB simulation the importance of waiting time parameter in controlling number of delivered frames and throughput. The results show that based on the exponential relationship between throughput and data traffic, there is a logarithmic relationship between data traffic and waiting time, which complements another logarithmic relationship between throughput and waiting time. The simulation also shows that there is an inverse relationship between throughput and data traffic as a function of set waiting time. The simulation shows that there is an exponential relationship between waiting time and maximum number of delivered frames. The work shows that a linear region of operating Slotted ALOHA can be specified, such that an optimum and dynamically adjusted waiting time is set with overall effect on number of slots and throughput. The dynamic shape function of the curve correlating waiting time to available number of slots is mathematically modelled and differentially controlled, thus an optimizing and controlling algorithm is produced, which improves significantly the conventional ALOHA performance and has an advantage over other used ALOHA derivatives, in that it concentrates on available slots and waiting time, which greatly contributes towards reduction in collisions and improving of throughput.

Keywords: Intelligent transportation system, Slotted ALOHA, Connected vehicles, Waiting time, Network connectivity, Slot number.

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1. Introduction

Vehicular networks and vehicular communication is an effective contributor to improve road safety and traffic management efficiency [1-3]. It is an important component of intelligent transportation systems (ITS), which embodies many applications such as intelligent driving, emergency message and basic safety message (BSM) transmission assistance. This will contribute towards safer, easier, and more reliable and comfortable driving. In addition, vehicular connectivity will result in lower fuel consumption and will assist in reducing traffic congestion [4, 5].

Various technologies exist have been for vehicular communication and their networks, including vehicle-to-vehicle (V2V) communications, vehicle-to-infrastructure (V2I) communications, or a combination of them. In V2V communication, vehicles exchange data such as including position, speed, and event-related information periodically. While V2I communication allows vehicles to communicate with roadside units (RSUs) within the infrastructure to coordinate and exchange data. Under certain circumstances, V2V/V2I network is formed and allow a vehicle to connect with the roadside infrastructures with a single or multi-hop arrangement [6, 7].

Vehicular communication occurs as a result of vehicular ad-hoc networks (VANETs), with message broadcasting resuming a vital role in contributing towards safer roads and helping in avoiding accidents and incidents. Message or beacon broadcasting faces many challenges due to mobility and the dynamic nature of vehicular connectivity and networking [8-9].

VANETs implement applications under three main areas:

(1) Safety
(2) Transport efficiency
(3) Infotainment

For VANET applications to be implemented using vehicular connectivity and wireless communication, there is a need for a medium access control (MAC) protocol with random access (RA) and ability for multi-access [10].

MAC is essential for VANETs safety and non-safety applications, as it supports efficient broadcast service allows sharing of such service by different vehicles. MAC protocol specifies when a vehicle (node) can transmit, and when it is expected to receive data. Thus, multiple nodes (communicating vehicles) will use a common channel to communicate (transmit and receive data). Sharing a communication channel, will open a chance and probability for collision, thus reducing throughput [11-14].

In multi-user communication networks, the communication medium is shared by network users that need to compete for access. In wireless networks, nodes use carrier sensing multiple access collision avoidance (CSMA/CA), or multiple access collision avoidance (MACA) as a MAC protocol, in order to reduce probability of collision. However, for wireless ad-hoc networks and VANETs, carrier sensing is not effective, due to inability of vehicles (nodes) to sense other vehicles presence [15].

The Aloha protocol is a random access medium protocol that does not carry out carrier sensing. Slotted-ALOHA protocol enhances communication channel utilization of the through organizing and synchronizing the transmission of devices within time-slots.

Thus, there is a need for channel- access method to avoid or at least reduce collision, while allowing channel sharing among vehicles. Slotted ALOHA is suitable distributed random access scheme where the link time is divided into slots of equal duration and the users contend to access the transmission channel by capturing a slot [16].

As a medium access control (MAC) protocol, Slotted ALOHA can be used for wireless and mobile multiple access networks such as VANETs. It has the advantage of simple implementation, with low access delay for small networks with low traffic. Thus, it is nowadays considered for general machine to machine (M2M) network applications. Due to the limitation of Slotted ALOHA regarding the size of network, the throughput of applying it is low at medium to high network densities [17, 18].

In the conventional Slotted ALOHA, each vehicle (node) would transmit at the start of a time slot with a specific probability. If no other node attempts to transmit, transmission will proceed with high probability of success. If more vehicles (nodes) attempt to transmit data, the probability of collision increases. It is proposed that a dynamic adjustable probability can resolve the collision issue [19, 20].

In this work an investigation of the effect of the available number of slots and waiting time is investigated. The work concentrates on the effect of total number of slots and waiting time on throughput and data traffic. The objective is to try and optimize these parameters, in order to reduce probability of collision and establish a dynamically changing ratio of waiting time to number of slots, and enable the selection of optimum waiting time in a vehicular and connected environment. This will enable obtaining of highest throughput. The work presents correlating expressions, which tie waiting time to the provision of number of slots in a dynamic manner. It also, provides a shape function control mechanism, through rate of change of waiting time in accordance to the available number of slots.

The rest of this paper is divided as follows: Related works, methodology, results and discussion, conclusions, references.

2. Related work

With the use of basic safety messages (BSMs), vehicle-to-vehicle (V2V) communication can wirelessly communicate location and speed information to nearby vehicles. This technology has a lot of potential to reduce traffic congestion, help prevent collisions, and enhance the environment. But the greatest advantages are only possible if all automobiles are able to communicate with one another [21, 22].

Using V2V communication, vehicles can exchange data remotely about their position, direction, and speed. At a pace of ten messages per second, vehicles may transmit and receive omnidirectional messages, giving them a 360-degree understanding of one another. Vehicles equipped with the appropriate software (or safety programs) can use the communications from nearby vehicles to detect potential collision hazards as they materialize.

Then, to alert drivers, the device can employ any combination of audible, tactile, and visual alarms, or just one of them. In response to these indications, drivers can take appropriate action to avoid collisions [23, 24].

The BSM messages that are sent have a range exceeding 300 meters and are capable of detecting dangers resulting from weather, topography, or traffic. V2V communication is used to expand and enhance the current accident avoidance systems, which use cameras, radars, Lidar, and other sensors to detect possible collisions. Instead than only surviving crashes, drivers can now completely prevent them with the help of this innovative technology. V2V communication technology may be used by automobiles, trucks, buses, and motorcycles.

The implementation of 5.9 GHz dedicated short-range communications (DSRC) on fleets of vehicles for wireless connectivity has been widely considered.

Vehicle-to-vehicle (V2V) communication that is enabled by DSRC and allows for the broadcast of basic safety messages (BSMs) opens up safety applications for crash avoidance and warning. However, when the V2V deployment grows in crowded traffic situations, the ensuing channel load rises, causing channel congestion that could negatively impact the effectiveness of the safety applications [25].

A wireless vehicular communication system enables engineers to create the next generation of advanced driver assistance systems (ADAS) based on advanced driver control systems (AVCS), which will allow drivers to share information using basic safety massages, about their own cars and the surroundings. Vehicular communication data also give us the best measurements on critical vehicle data like speed, yaw rate, and steering angle, which are obtained directly from other vehicles. When vehicles, road side units (RSUs), and road users are equipped with wireless communication devices, the communication network's range can be increased [26].

A proposed multi-channel vehicle-to-vehicle (V2V) communication system that dynamically chooses the optimal channel for the transmission of safety messages while monitoring all available channels is researched. While driving normally, the proposed technique tracks sporadic beacons from other cars and calculates the communication latency across all channels. When possible collision is detected, it uses a unique channel negotiation approach that enables all of the participating vehicles to cooperate in a dispersed fashion to find a communication channel that satisfies the delay requirement. This will enable a more efficient BSM exchange [27].

To efficiently manage intelligent transportation systems using wireless communications and BSMs, one of the most promising technologies has been identified: the vehicle ad hoc network (VANET). In order to address communication congestion issues that may emerge in VANETs, distributed transmission power adjustment method for control of communication congestion and awareness augmentation is proposed. Such technique, if applied, should in theory keep the communications channel load below the permitted threshold while offering the greatest awareness of the status of neighbouring vehicles [28].

To ensure extra driving safety, autonomous vehicles must also have the capability to cooperate with surrounding vehicles; nevertheless, planning and adhering to the intended trajectory whilst taking into account the nearby vehicles is a complex task, as the vehicle programming requires to understand the human driver behaviour and reaction to receiving BSMs [29].

Vehicle-to-vehicle (V2V) communication technology can improve the effectiveness of safety systems and perhaps save lives. With the use of connected car technologies, drivers will be able to predict possible collisions and drastically lower the annual death toll.

V2V communication technology has the potential to improve car safety system performance and save lives. Thanks to linked car technologies, which will provide drivers with the tools they need to anticipate future incidents, the number of fatalities each year will be significantly decreased.

Designing and developing new wireless technologies is always necessary to keep up with the growing demands for high-speed wireless data transfer and the integration of sophisticated intelligent transport systems. A variety of wireless technologies, such as cellular standards for short- and long-range, are constantly developing. These new technologies have the potential to significantly improve vehicular communication's operating performance [30].

Vehicle-to-vehicle (V2V) communication happens opportunistically in vehicular ad hoc networks (VANETs) as a result of frequent node mobility and sporadic contact time. Given the many approaches that the routing protocols take when determining the next hop, evaluating the performance of the forwarding protocols in this scenario by utilizing the resources already present in the network requires balanced approach [31].

In order to assure road safety and accomplish secure communication, vehicular ad hoc networks, can use "mobile internet" to promote communication between vehicles. Therefore, the dependability of these kinds of networks is crucial. Safety-related signals are distributed using vehicle-to-vehicle (V2V) and vehicle-to-roadside (V2R) wireless communications within VANETs. Thus, network reliability is a crucial prerequisite. The impact of vehicle density and transmission range on the probability of connectivity important. Furthermore, a minimal safe headway among neighbouring vehicles at a highway tunnel should be taken into consideration [32].

Many wireless access solutions that enable radio interface between vehicles and between infrastructure and vehicles, enable VANET connection. These communications support safety as well as non-safety applications. These technologies can facilitate communication between the vehicle nodes by using centralized infrastructure or ad hoc methods. The interconnection and interoperability requirements are addressed via communication standards, which enables systems such as Dedicated Short Range Communication using WAVE to be applied [33].

Advanced localization and navigation systems, are all provided by modern intelligent transportation systems (ITS), which includes connected and autonomous vehicles (CAVs). The main components of a standard ITS system are road-side units (RSUs) and vehicle onboard units (OBUs). Automotive sensors, V2X communication modules, and CPUs for communication and driver-assistance systems make up modern RSUs [34].

The development of high-speed communication technologies (5G and 6G) and the internet of things (IoT) has led to the rapid advancement of (CAVs). The development of intelligent transportation systems to enable sustainable and green smart cities will be greatly aided by CAV systems. Transportation systems that are intelligent, sustainable, and improve the environment will benefit from this [35, 36].

Wider sensor ranges and multi-access edge designs in CAV communication networks will allow for more effective use of various frequency spectrum modes. Concurrent use of services that, among other things, shorten travel times, enable cooperative autonomous driving, save infrastructure and maintenance costs, and boost energy efficiency. The primary concerns of modern advancements include data storage, privacy and security challenges, IoT sensor energy optimization in cars, legal uncertainties, and real-time big data analytics [37–39].

Due to signal intensity change, which is influenced by the environment and the quality of the communication channel, V2V communication may experience delays that result in significant loss and bandwidth limitations. Since drivers must communicate with the human-machine interface (HMI), these issues also involve the human element. Reacting to signals sent by the on-board unit (OBU) and responding to data obtained through the vehicle management systems are examples of this type of interaction. It can potentially have technical issues as a result of processing and message delivery delays. The propagation and communication time between vehicles, which may be hampered by topographical or technological issues, are also related to the processing of any received BSM.

A communication network channel is used to send data using the multiple access protocol ALOHA. The network seven layer model's medium access control (MAC) sublayer is where it operates. Through a multi-point transmission channel, this protocol enables the transfer of many data streams emanating from different nodes (vehicles) [40]. However, the presented work has the advantage over the work in [40], in that it provides dynamic relationship, which enables parameters balancing and optimization, through control of the shape function.

Without attempting to ascertain whether the transmission channel is empty or busy, every node in the ALOHA communication network delivers a frame. If the channel is vacant, the data transfer will be successful. When two nodes transmit data simultaneously, the data will collide and be rejected. Until a transmission is successful, the communication nodes (vehicles) may transmit again [41]. The presented work allows for waiting time to change in response to number of slots, which in effect reduces collision and improves throughput.

ALOHA based solutions can be utilized for broadcast services in automotive connectivity via vehicular ad-hoc networks (VANETS). In order to facilitate the exchange of basic safety messages (BSMs) between vehicles and between vehicles and infrastructure, the broadcast is required. Due of its ability to comparatively prevent collisions through the allotted slot strategy, slotted ALOHA is interesting. Researchers provide a modified version of Slotted ALOHA called VeMAC, in which conflicting slots are given up to the colliding vehicles (nodes) [42–44]. The presented work has the advantage of its ability to control conflict between slots, through balancing of available slots to waiting time.

Other researchers discovered that VeMAC had a high collision rate and suggested slotted ALOHA that is logically centralized (LC-SA). It is stated that the suggested method gives higher throughput than VeMAC and fixes collision-related problems by regulating the slot release and increasing the success rate of channel accessibility. Some researchers have developed a low complexity dynamic frame slotted Aloha (DFSA) anti-collision algorithm, called LC-DFSA, in response to the high complexity and low efficiency of many conventional ALOHA based algorithms [45]. The latest frame size, the number of contributing slots, and the account of idle slots can all be used by the method to estimate the range of tag numbers. That being said, this method resolves the VeMAC collision problems. The presented approach, and through differential relationship between waiting time and number of slots, can improve throughput to an optimized level.

Vehicles must have effective MAC protocols in order to share wireless communication channels with VANETS' dynamic network topologies. Thus, in order to facilitate the prompt acquisition of packet transmission slots by cars wishing to transfer data, researchers created a protocol. The distributed algorithm, known as ResVMAC, is a slot reservation algorithm [46]. The delivered packet ratio suggests that the suggested protocol is more efficient than traditional ALOHA, although the authors did not address time response in detail. Instead, they focused on packet delivery ratio, which demonstrates strong performance. The presented work, has the reservation feature embedded with dynamic nature, as it reserves slots in accordance to communication channel activities and adjusts waiting time accordingly.

Researchers found that using a hybrid non-orthogonal multiple access with ALOHA can overcome the problems with low throughput and collisions that come with standard ALOHA [47]. The work talks about sum throughput, which will result in substantially greater values if used in the work. The novel method uses random access (RA) multichannel ALOHA, where nodes can choose different power levels to transmit data, to address ALOHA concerns caused by NOMA, as it has been presented in several publications [48, 49].

3. Methodology

The atmosphere of vehicles creates problems for communication protocols in terms of efficacy, efficiency, and dependability. The prompt and effective delivery of emergency alerts, including basic safety messages (BSMs), is essential for traffic management and congestion reduction. This necessitates the optimal use of the shared communication medium in order to ensure efficient communication channel sharing. Improved channel access will be made possible via media access control (MAC). Throughput per shared channel will increase with MAC protocol efficiency.

On-board units (OBUs) are installed in vehicles to facilitate inter-vehicle communication in VANETs. Unicast, multicast, and broadcast communication can be used for single-hop or multi-hop communication with other vehicles or roadside units (RSUs). Improved communication channel design and implementation will be made possible by modelling and simulating vehicle interaction [50-54].

This work considers a number of vehicles communicating their BSMs and both Normalized offered traffic (G) and Throughput (S). The considered vehicular network has the following properties:

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_{slot}.
3. Each frame is assigned an N number of slots.
4. An error is assumed in the transmission if two or more data frames interfered.
5. It is assumed in the simulation that each node knows at the end of transmission if it is successful.

The work simulates Slotted ALOHA using MATLAB in order to investigate effect of the following parameters on efficiency of vehicular communication using Slotted ALOHA protocol in the cases of connected and autonomous and connected vehicles:

1. Waiting time (T_w)
2. Number of slots N

The symbols/acronyms and their meaning presented in Table 1.

4. Results and discussion

In the Slotted ALOHA, throughput is assumed maximum according to Eq. (1). Fig. 1 shows the optimum throughout response as a function of slot probability computed as in Eq. (1)

$$P_{slot} = 1/V \tag{1}$$

It is also assumed that the maximum throughput at optimum slot probability (Pslot), can be approximated as in Eq. (2).

$$S = \left(\frac{V}{2V-1}\right) \tag{2}$$

Table 1. Nomenclature

Symbols/ Acronyms	Meaning
V	Nodes Number: Number of vehicles that generate packets (data frames).
P_{slot}	Packet probability: the probability that a specific node has a packet ready to be transmitted at a particular time slot.
S	Throughput of the slotted ALOHA random access protocol.
T_w	Slot waiting time.
G	Normalized available traffic, with retransmissions included.
N	Number of slots.
F_{max}	Maximum number of delivered frames.

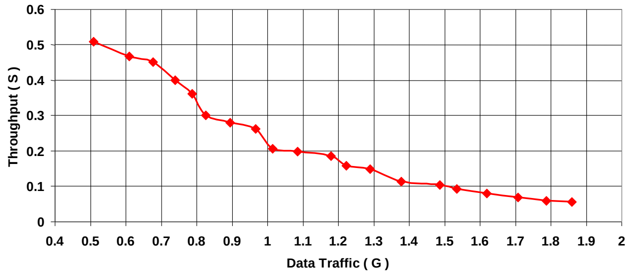

Figure. 1 Relationship between data traffic and throughput

Based on Eqs. (1) and (2), and using a vehicular cloud of 20 vehicles results in Pslot=0.05, and Smax=0.51.

These calculations are proved through the initial simulation, using Pslot=0.05, results in maximum throughput shown in Fig. 1 as a function of data traffic.

From Fig. 1, Eq. (3) is obtained, which describes the behavior of throughput as a function of data traffic.

$$S = \lambda exp(-\kappa G) \tag{3}$$

Where; $\lambda \geq 1.3, \kappa \geq 1.7$

Based on the previous initial setup, two cases are considered:

4.1 Effect of waiting time (T_w)

Figs. 2-11 show the relationship between the delivered numbers of frames as a function of waiting time, with N=20000.

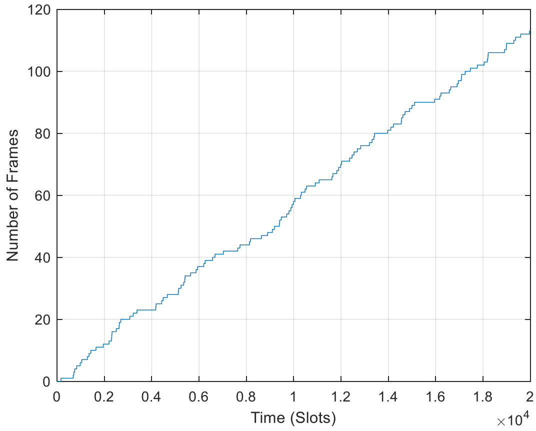

Figure. 2 Successful transmission as a function of T_w=200 Slots

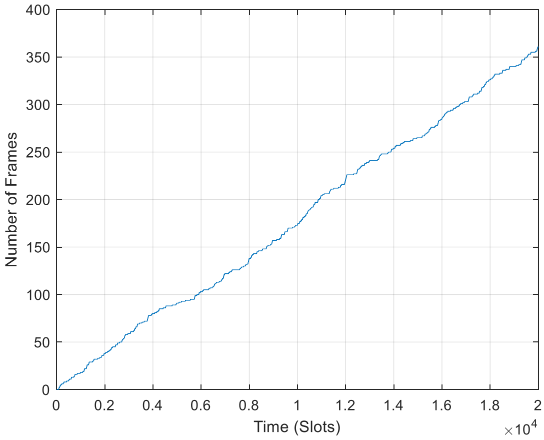

Figure. 3 Successful transmission as a function of T_w=400 Slots

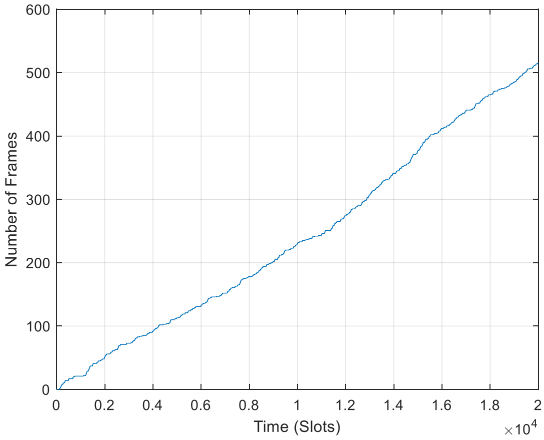

Figure. 4 Successful transmission as a function of T_w=600 Slots

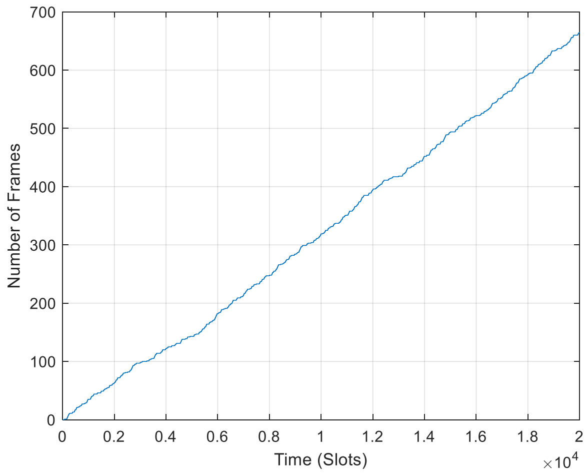

Figure. 5 Successful transmission as a function of T_w=800 Slots

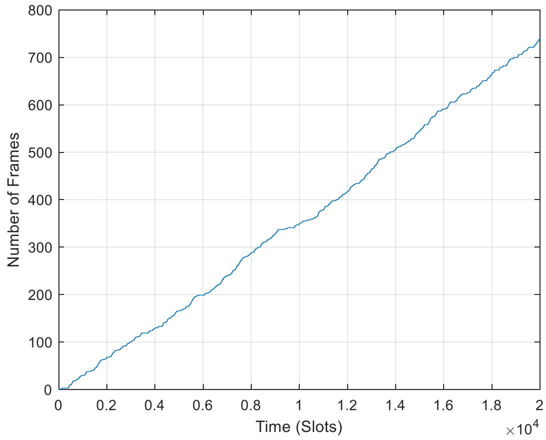

Figure. 6 Successful transmission as a function of T_w=1000 Slots

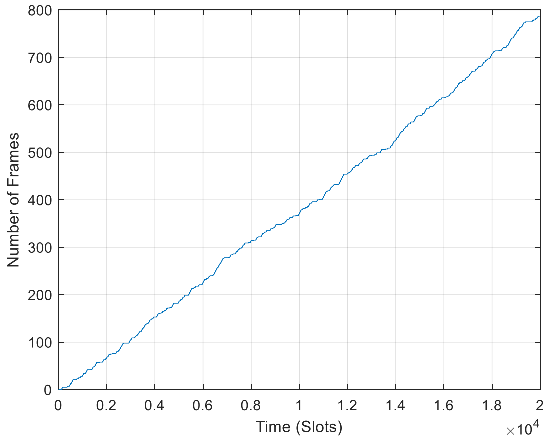

Figure. 7 Successful transmission as a function of T_w=1200 Slots

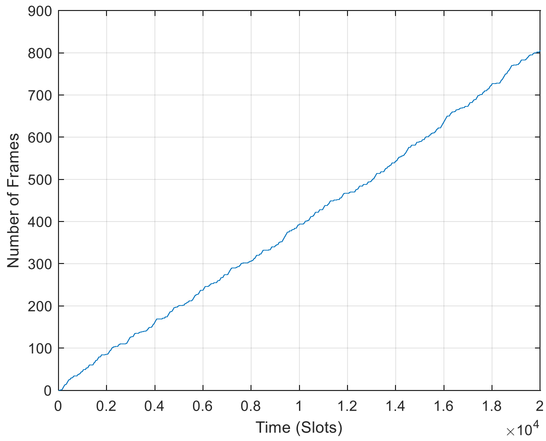

Figure. 8 Successful transmission as a function of T_w=1400 Slots

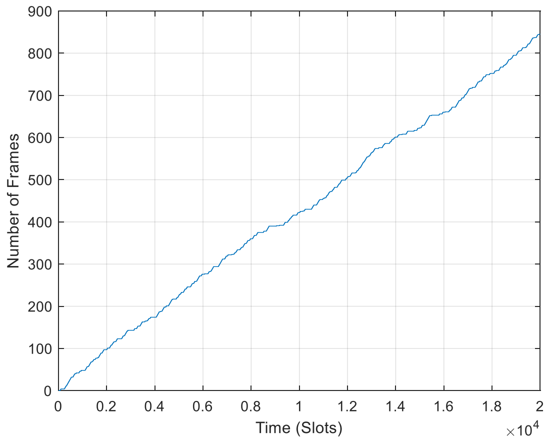

Figure. 9 Successful transmission as a function of T_w=1600 Slots

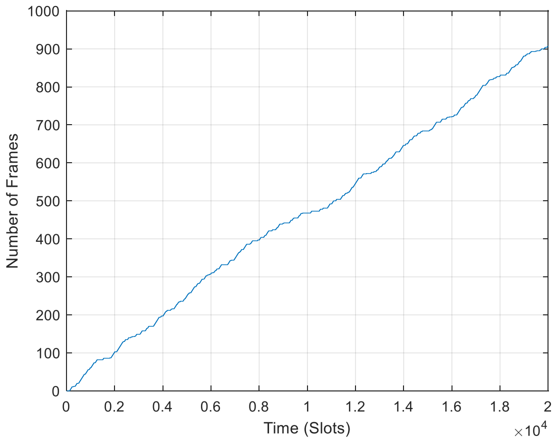

Figure. 10 Successful transmission as a function of T_w=1800 Slots

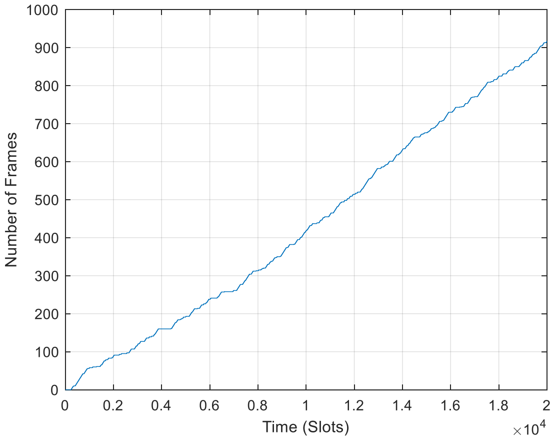

Figure. 11 Successful transmission as a function of T_w=2000 Slots

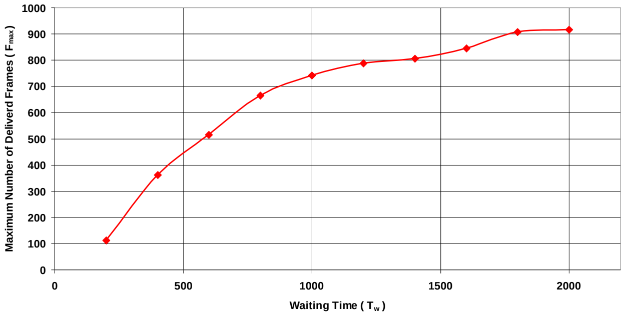

Figure. 12 Relationship between maximum successfully transmitted frames and waiting time

Fig. 12 show the overall function describing the relationship between maximum numbers of delivered frames (Fmax) and dynamically changing waiting time (T_w). The plot shows the logarithmic relationship relating F_{max} as a function of Tw. The relationship is described by Eq. (4), and shows that as waiting time increases, so does the maximum number of delivered frames. This is due to the dynamic change in the required number of slots to accomplish transmission.

$$F_{max} = \rho \log_e T_w - \mu \tag{4}$$

Where; $\rho \leq 355, \mu \leq 1750$

Fig. 13 shows effect of waiting time (T_w) on average data traffic (G). From the plot, it is evident that as the waiting time increases, the average data traffic ($G_{average}$) decreases, as a result of the increase in frames delivery rate. The natural logarithmic relationship is presented in Eq. (5).

$$G_{average} = -\psi \log_e T_w + \phi \tag{5}$$

Where;$\psi \leq 0.25, \phi \geq 2.5$

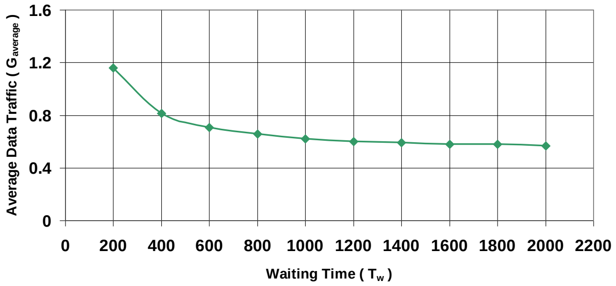

Figure. 13 Relationship between waiting time and average data traffic

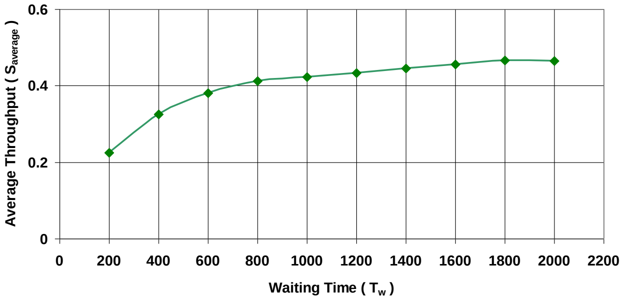

Figure. 14 Relationship between waiting time and average throughput

Fig. 14 complete the overall view in the case of connected vehicles, by showing the average throughput ($S_{average}$) as a function of waiting time. The plot shows an increase in throughput as a result of delivering so many frames and acts as a complementary function to the average data traffic presented in Eq. (5), as shown in Eq. (6).

$$S_{average} = \eta \log_e T_w - \varepsilon \tag{6}$$

Where; $\eta \geq 0.1, \varepsilon \leq 0.3$

4.2 Effect of number of slots

Figs. 14-19 show the relationship between the delivered numbers of frames as a function of dynamically changing total number of slots (N), with Tw=200, while Figs. 20-24 show the same relationship for Tw=2000.

Fig. 25 shows a comparison between the average data traffic for two different waiting times, and as a function of total number of slots (N). The plot clearly shows that as the waiting time increases, average data traffic decreases. Also, it is evident that for each Tw value, the average data traffic does not change much over different number of slots. This indicates that the controlling parameter is Tw rather than number of slots (N). Also, for the average data traffic for Tw=200 is almost twice that for Tw=2000.

The comparison in Fig. 25 is complement by the relationship shown in Fig. 26, whereby the average

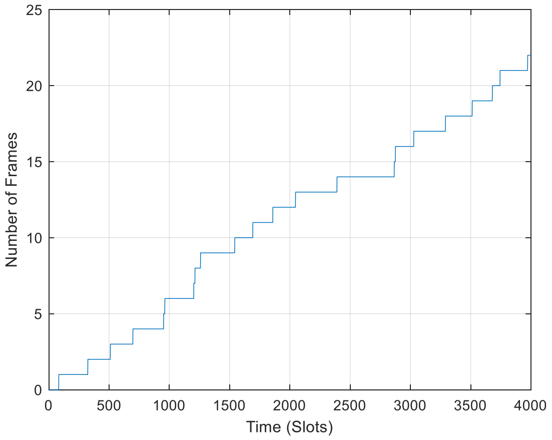

Figure. 15 Successful transmission as a function of N=4000

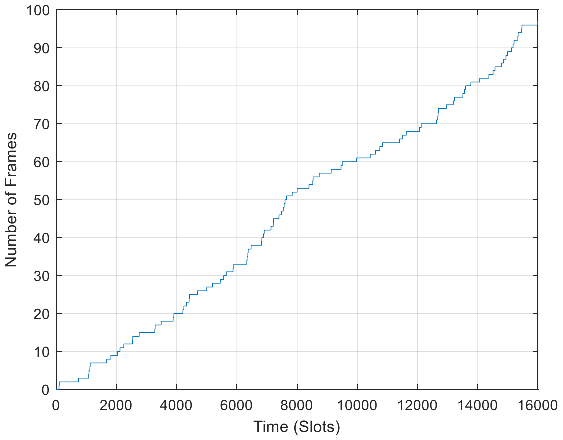

Figure. 18 Successful transmission as a function of N=16000

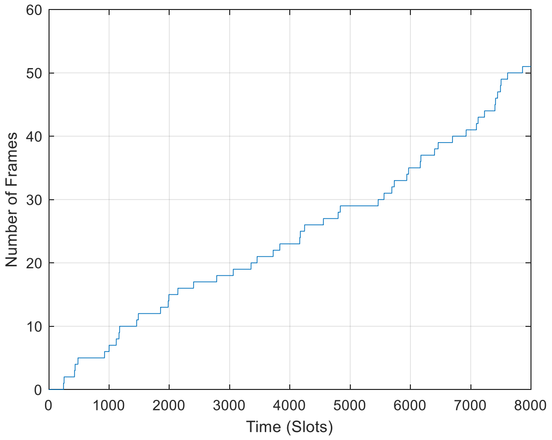

Figure. 16 Successful transmission as a function of N=8000

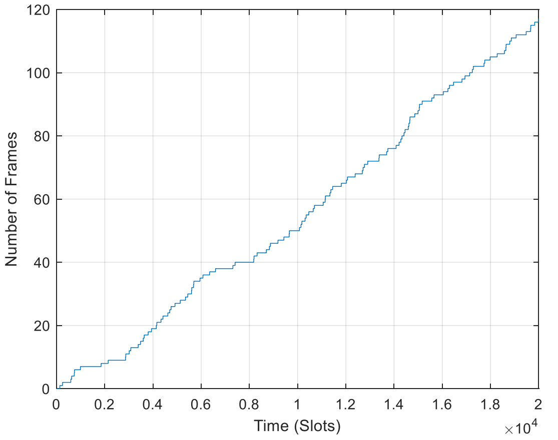

Figure. 19 Successful transmission as a function of N=20000

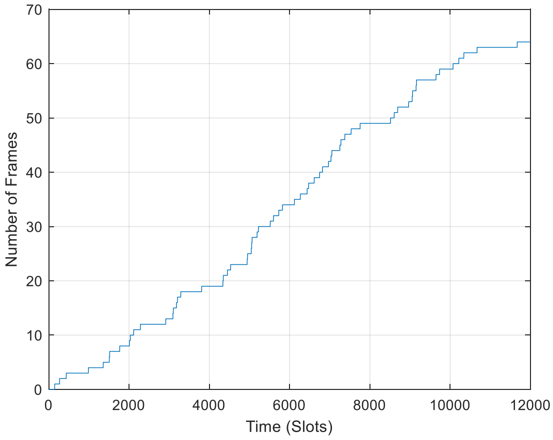

Figure. 17 Successful transmission as a function of N=12000

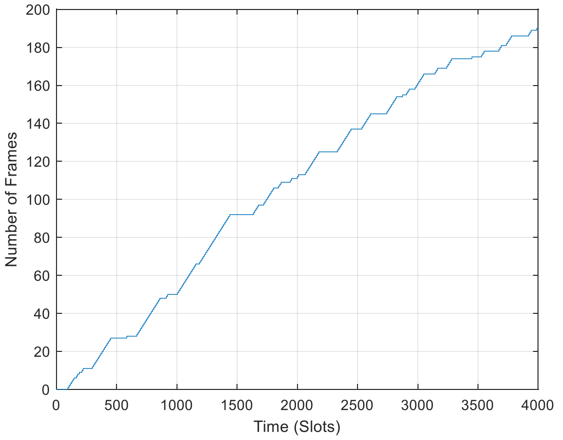

Figure. 20 Successful transmission as a function of N=4000

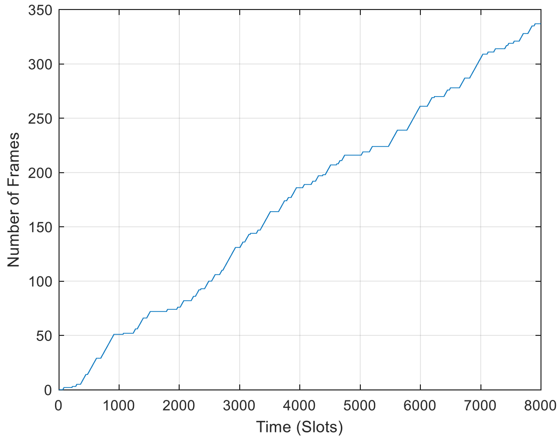

Figure. 21 Successful transmission as a function of N=8000

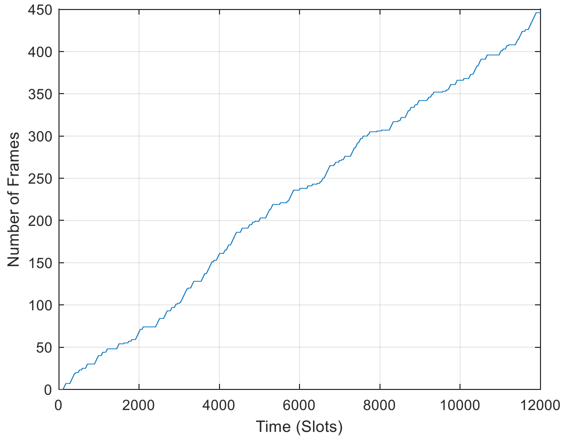

Figure. 22 Successful transmission as a function of N=12000

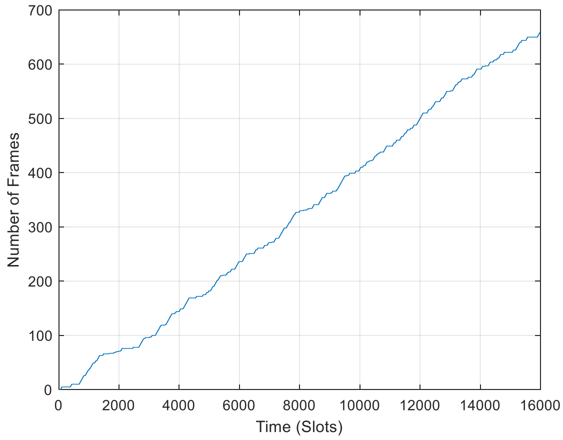

Figure. 23 Successful transmission as a function of N=16000

throughput for Tw=2000 is almost twice that for Tw=200. This confirms that the controlling factor in Slotted ALOHA is the waiting time and not total number of slots (N).

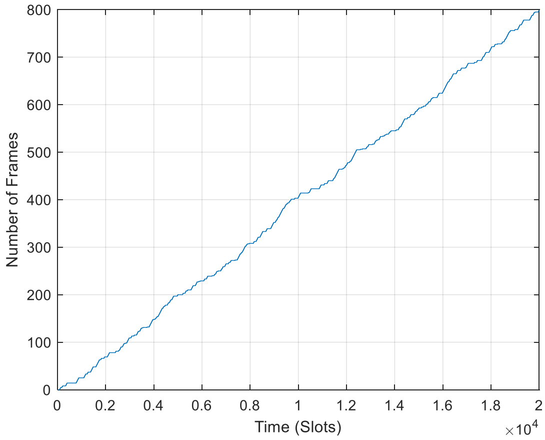

Figure. 24 Successful transmission as a function of N=20000

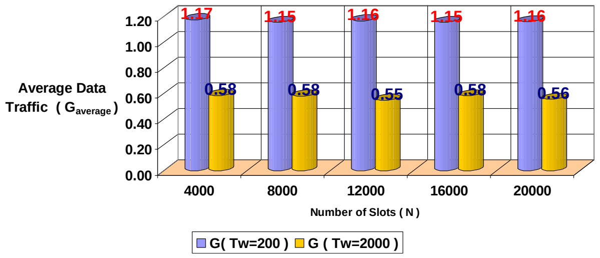

Figure. 25 Relationship between average data traffic and Number of slots

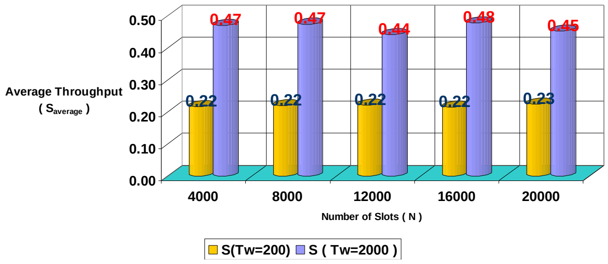

Figure. 26 Relationship between average throughput and Number of slots

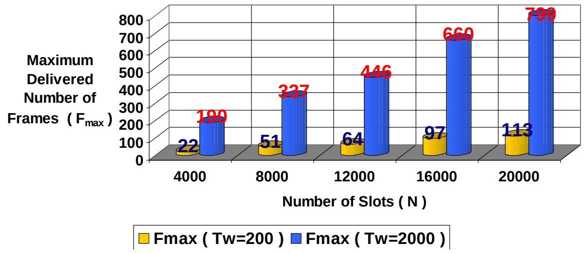

Figure. 27 Relationship between maximum delivered number of frames and Number of slots

From the plots in Figs. 25 and 26, Eqs. (7) and (8) are obtained.

$$G_{average}(T_w = 200) = 2G_{average}(T_w = 2000) \quad (7)$$

$$S_{average}(T_w = 2000) = 2S_{average}(T_w = 200) \quad (8)$$

Using Eqs. (3), (8), and (9) is obtained:

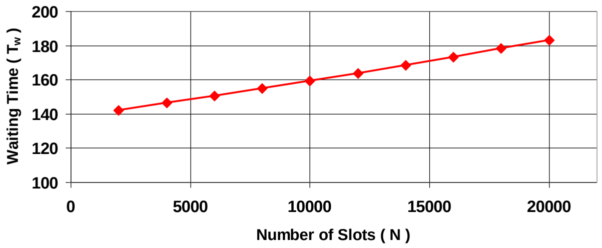

Figure. 28 Relationship between waiting time and number of slots

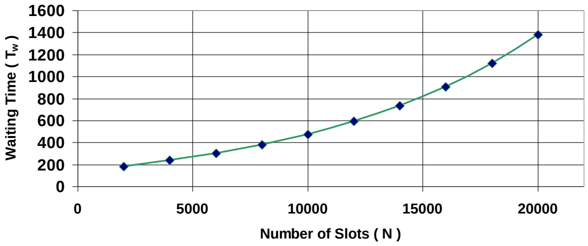

Figure. 29 Relationship between waiting time and number of slots

$$S_{average}(T_w = 2000) = 2\lambda exp(-\kappa G) \tag{9}$$

Fig. 27 show a comparison for maximum number of delivered frames (F_{max}) for T_w=200 and T_w=2000 slots. Eq. (10) describes such relationship.

$$F_{max} = \delta N^{\upsilon} \tag{10}$$

$Where; \delta \geq 0.005, \upsilon \geq 1 \text{ for } T_w = 200$

$Where; \delta \geq 0.11, \upsilon \leq 0.9 \text{ for } T_w = 2000$

Using Eqs. (4), (10), and (11) is obtained.

$$T_w = exp\left(\frac{\delta N^{\upsilon} + \mu}{\rho}\right) \tag{11}$$

$Where;\ \rho \leq 355, \mu \leq 1750$

Applying the limits in Eqs. (4) and (10), a plot can be obtained for both maximum waiting time of 200 (T_w=200) and maximum waiting time of 2000 (T_w=2000), as shown in Figs. 28 and 29.

The plots in Figs. (28) and (29) indicates that as the upper limit of waiting time increases, the relationship between the waiting time and total number of slots becomes exponential. Thus, it is better to modify the ALOHA algorithm to use waiting time to total number of slots ratio to dynamically respond to different requests of access to the network and transmission readiness. Also, there is a need to keep waiting time in the linear region, and that can be achieved by adjusting the ratio, to obtain optimum throughput.

Using Eqs. (4) and (10), Eq. (12) is obtained.

$$\delta N^{\upsilon} = \rho \log_e T_w - \mu \tag{12}$$

From Eq. (12), a relationship between number of slots (N) and Waiting time (T_w) is obtained, as presented in Eq. 13.

$$N = \left(\frac{\rho \log_e T_w - \mu}{\delta}\right)^{-\upsilon} \tag{13}$$

Eq. 13 shows the dynamic relationship between number of slots (N) and waiting time (T_w). Thus the used simulation algorithm presents an optimization approach that enables adaptive adjustment of number of available slots and connections as a function of waiting time. This will optimize communication over the connecting channel and should result in a higher throughput per channel with lower congestion levels and lower data collision rate. In addition, using Eqs. 11 and 13, enables control on the shape function and its change rate.

From Eq. 11, the change in waiting time with respect to number of slots for optimum performance and dynamic change is presented in Eq. 14.

$$T_w = exp\left(\frac{\delta N^{\upsilon}}{\rho} + \frac{\mu}{\rho}\right) \tag{14}$$

From Eq. 14, Eq. 15 is obtained.

$$T_w = exp(\psi N^{\upsilon} + \phi) \tag{15}$$

Now, selecting υ to be 1, as a middle value between N=200, and N=2000, and taking the derivative of waiting time with respect to number of available slots, yields Eq. 16.

$$\frac{dT_w}{dN} = \psi * exp(\psi N + \phi) \tag{16}$$

The parameter ψ, controls the rate of change of the exponential function and dynamically correlates waiting time to number of slots, which in turn affects throughput and maximum transmitted number of frames.

5. Conclusions

This work investigates through simulation effect of waiting time and total number of slots using Slotted ALOHA and its effect on throughput and data traffic. The work presented mathematical model that can be used in order to dynamically and adaptively modifies throughput parameters based on adjusting waiting time and total number of slots. Thus action will result in reduction in the collision rate usually associated with higher vehicular connectivity.

Dynamic adaptive approach is necessary for efficient application of Slotted ALOHA, with concentration on waiting time as it can be used as an effective controlling parameter for more effective random access technique in vehicular communication. Thus, the approach in this work through MATLAB simulation and mathematical modelling, provides a reliable and efficient algorithm that enables a more efficient ALOHA performance, through consideration of waiting time relationship with number of provided slots, such that an adaptive communication channel and effective network communication can be achieved. In addition, the shape function describing the behaviour of the communication system, through the differential relationship between waiting time and number of slots is presented and greatly supports a more effective connectivity. All of that is related to throughput, which is improved as availability of slots is adjusted dynamically.

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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