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Adaptive Vehicular Communication using ALOHA CSMA with Modified Logistic Function (ALOHA$_{\text{MLF}}$)

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Abstract: The objective of this work is to mathematically model vehicular connectivity using ALOHA base function with modified logistic function as an adaptive control function. The focus of this work is to utilize the ALOHA protocol as a carrier sensing multiple access technique and add to it an intelligent part, which is the modified logistic function (MLF) to enable adaptive communication channel. The work correlates three time based parameters related to vehicle, communication, and human driver, which are associated with connected vehicles (driver response time, machine processing time, and channel communication time). The mathematical model showed that throughput for autonomous and connected vehicles is much higher than that for connected vehicles due to the elimination of human time factor, together with the evident low response time from sensors, electronics, and communication. In addition, a more stable connectivity is established if human element is not part of the model, as this eliminates both uncertainty and lengthy human response time. The ALOHA function role is to enable continuous tries by each node (vehicle) to establish communication with probability related to availability of communication channel and a back off functionality in case of collision. The proposed model provides dynamic and adaptive technique to adjust time slots using the continuous change in the vehicular connectivity environment, which affects the presented time parameters, thus changing frames delivery pattern and time slots utilization. The presented approach, supports better and more efficient use of communication channel, particularly in the case of autonomous and connected vehicles. It also, highlights through comparison the inhibitory effect driver actions can have on safe driving, through time delay, and low communication channel utilization. In addition, the work also focusses on the effect of processing time for sensors and electronics, which also have negative effect on channel usage and effectiveness, if there is a functional problem.

Keywords: Connected vehicles, Intelligent transportation system, Sigmoid function, AVCS, ADAS, Wireless communication, HMI, Autonomous vehicles, Cooperative driving.

1. Introduction

If a vehicle has network and internet connectivity, it is said to be connected since it can share data with other vehicles, homes, offices, and infrastructure as well as other devices inside and outside the vehicle.

The data from connected vehicles offers the chance to monetize captured data using several techniques. The utilization of the vehicle data can enhance the experience and safety of the driver and passengers, introduce new services, and improve vehicle performance. Some of the applications vehicular data are [1-5]:

1. User characteristics based insurance.
2. Intelligent maintenance through predictive algorithms.
3. Dynamic and mobile upgrades and software updates.
4. Safety applications through Vehicular communication.
5. Intelligent traffic management through vehicular communication.
6. Assistance systems.
7. Infotainment.

Vehicle-to-vehicle (V2V) communication has the potential to wirelessly transmit data regarding the speed and location using basic safety messages

(BSMs) to surrounding vehicles, which holds great promise for assisting in collision avoidance, easing traffic congestion, and improving the environment. The biggest benefits, however, can only be attained when all cars are capable of communicating with one another [6-8].

Vehicles can remotely communicate data regarding their direction, location, and speed using V2V communication. Vehicles may send and receive omnidirectional messages at a rate of 10 messages per second, which enables them to have a 360-degree knowledge of each other. The communications from neighbouring vehicles can be used by vehicles with the proper software (or safety applications) to identify possible crash dangers as they emerge. The device can then use a combination of audio, tactile, and visual alerts—or any one of them alone—to warn drivers. Drivers are able to take action in response to these signals to prevent collisions [9-11].

The exchanged BSM messages can detect risks caused by weather, topography, or traffic and have a range of more than 300 meters. The present accident avoidance systems, which employ radars, Lidar, cameras, and other sensors to identify potential collisions, are extended and improved via V2V communication. With the use of this new technology, drivers can avoid collisions altogether rather than just surviving them. Vehicles including cars, trucks, buses, and motorbikes could all employ V2V communication technology [12-16].

V2V communication technology can increase the performance of vehicle safety systems and help save lives. Connected vehicle technologies will provide drivers with the tools they need to anticipate potential crashes and significantly reduce the number of lives lost each year.

The performance of vehicle safety systems can be improved via V2V communication technology, potentially saving lives. The number of fatalities each year will be greatly reduced thanks to connected car technologies, which will give drivers the resources they need to foresee future collisions [17-20].

Connected and autonomous vehicles (CAV) are fast developing due to the development of internet of things (IoT) and high speed communication technologies (5G beyond and 6G). CAV will significantly contribute to the creation of smart transportation systems to support green and sustainable smart cities. This will support better environments, intelligent, and sustainable transportation systems [21-24].

CAVs communication networks will have a wider range of sensors and multi-access edge configurations, enabling more efficient utilization of different frequency spectrum modes. The simultaneous use of services that reduce travel time, allow for cooperative autonomous driving, lower maintenance and infrastructure costs, improve energy efficiency, among other benefits. Data storage, privacy and security concerns, IoT sensor energy optimization in vehicles, legal uncertainty, and real-time big data analytics are main issues of developments nowadays [25-30].

V2V communication can suffer from delay related to signal strength variation, which is related to surroundings and communication channel quality, causing high loss and limiting the available bandwidth. These problems are also related to the human element, as drivers need to interact with the designed human-machine interface (HMI). Such interaction involves reacting to delivered messages the on-board unit (OBU) and responding to information provided via the vehicle control systems. Which could also suffer from technical problems, due to message delivery delay and processing delay. Processing of any received BSM is also related to propagation and communication time between vehicles, which could suffer from technical and topographical problems.

This work is based on analysing and mathematically modelling effect of the driver response time together with effect of processing and communication on data throughput of data transmission. Such approach will greatly aid in improving the connected and connected and autonomous vehicles design and communication protocols. The presented work employs modified logistic function (MLF) and ALOHA based throughput function to enable analysis of human factor and its effect on throughput.

2. Related work

The multiple access protocol ALOHA is used to transmit data over a communication network channel. It functions over the medium access control (MAC) sublayer in the Network seven layer model. This protocol allows the transmission of several data streams coming from various nodes (vehicles) across a multi-point transmission channel [31-32].

Each node in the ALOHA communication network sends a frame without attempting to determine if the transmission channel is busy or empty. The data will be successfully transferred if the channel is empty. If two nodes send data at the same time, the data will suffer collision and will be discarded. The communicating nodes (vehicles) may repeatedly transmit until successful transmission takes place [33-34].

For vehicular connectivity using vehicular ad-hoc networks (VANETS), ALOHA based techniques can be used for broadcast services. The broadcast is necessary to enable basic safety messages (BSMs) to be exchanged between vehicles and between vehicles and infrastructure. Slotted ALOHA is of interest as it can be used to relatively avoid collisions using assigned slot approach. A modified version of Slotted ALOHA is presented by researchers, termed, VeMAC, where conflicting slots are abandoned for the collided vehicles (nodes) [35-37]. However, this technique which overcomes the conventional MAC collision issues did not take into account explicit contribution of driver response time, electronics and sensors times, and communication channel time. The maximum efficiency of this technique is reported to be close to 60%, compared to the adaptive technique presented in this work, which results in 50% for connected and 70% for autonomous and connected vehicles. In addition, slot time used in the simulation in [35] is 1mS, while in this work 100mS slot time is implemented. This means that for lower slot time, higher throughput would be obtained. Hence, if 1mS applied to this work simulation, a much higher throughput would result, based on the results obtained for 100mS slot time. Similar results obtained in [36] and [37].

Other researchers found that VeMAC suffers high collisions and proposed logically centralized slotted ALOHA (LC-SA). The proposed technique is claimed to resolve issues related to collisions by controlling the slot release and improving the rate of success of channel accessibility, and offers higher throughput than VeMAC. As many conventional ALOHA based algorithms suffer from low efficiency and high complexity, a proposed low complexity dynamic frame slotted Aloha (DFSA) anti-collision algorithm, (LC-DFSA) is proposed by some researchers [38]. The algorithm can estimate the range of tag numbers according to the last frame size, number of contributing slots and an account of idle slots. However, this technique which overcomes the VeMAC collision issues did not take into account explicit contribution of driver response time, electronics and sensors times, and communication channel time. The maximum efficiency of this technique is reported to be less than 40%, which is low compared to the obtained values in this work of 50% for connected vehicles, and 70% for autonomous and connected vehicles.

Effective MAC protocols are required for vehicles to enable efficient sharing of wireless communication channels using the dynamic network topologies in VANETS. Thus, researchers introduced a protocol that enables quick capture of packet transmission slots by vehicles that wish to transmit data. The distributed algorithm is a reservation algorithm for slots and termed ResVMAC [39]. The authors did not present throughput or efficiency in their work, instead packet delivery ratio is discussed, which shows good performance, but did not discuss time response in details, hence there is a claim based on delivered packet ratio, the proposed protocol is more efficient than conventional ALOHA. This protocol is suggested to be more efficient than other ALOHA-based protocols such as Reliable Reservation ALOHA (RR-ALOHA) and mobility adaptive RR-ALOHA (MARR-ALOHA) [40-41], where researchers also used packet delivery ratio to establish the proposed technique effectiveness compared to conventional ALOHA. No response time consideration is discussed in these works to enable direct comparison with our work.

The issues associated with conventional ALOHA in terms of collisions and low throughput can be resolved according to researchers using a hybrid non-orthogonal multiple access with ALOHA. This is termed ALOHA-NOMA [42]. The work discusses sum throughput, which if applied in work will produce much larger values. The new approach mitigates ALOHA issues by NOMA, as it has been presented in the different works using random access (RA) multichannel ALOHA, whereby nodes can select different power levels to transmit data [43-44], where the obtained throughput is comparable to the one presented in this work, but without consideration to detailed response time, or adaptive functionality.

Connected vehicles communicate with each other or infrastructure. A critical issue in vehicular communication is the shared medium and the dynamic change in vehicular density, which challenges the communication channels capacity. To face such challenges, random access techniques based on adaptive ALOHA are presented and discussed by different authors. These works cover techniques such as density-aware slotted ALOHA with access probability, Adaptive-opportunistic ALOHA, (FEC-ALOHA), which is ALOHA with forward error correction, and a time division multiple access (TDMA) switching with slotted ALOHA technique [45-50], where the reported throughput value of 55% is higher than the connected vehicles throughput reported in this work (50%), and lower than the autonomous and connected vehicles reported number of 70% in this work. The discussed work by the researchers did not take into account driver response time.

In this work, a new adaptive approach for using ALOHA with logistic function to characterize

Table 1. Nomenclature

Symbols/ Acronyms	**Meaning**
$T_d=T_{perception}+T_{reaction}$	This is the time duration from the moment the driver receives a message and realizes that there is a message to the time the driver takes an action regarding the information in that message
$T_m=T_{TX}+T_{RX}$	The needed time for the vehicle electronics and control devices (OBU) to process received data.
T_c	Communication channel time, which is affected by surroundings, routing, and the vehicular dynamic movements.
T_r	Driver Response time.
$T_{r\ (thresh)}$	The maximum allowed driver response limit.
T_p	Vehicle electronics and sensors processing time
$T_{p\ (thresh)}$	The maximum allowed electronics and sensors processing limit.
T_{com}	mobile and wireless communication channel data exchange time.
$T_{com\ (thresh)}$	The maximum allowed channel data exchange time limit.
ϕ	Adaptive driver response time with modified logistic control.
φ	Adaptive machine processing time with modified logistic control.
θ	Adaptive vehicular communication time with modified logistic control.
T_{conn}	Overall and correlated time for vehicular connectivity
S	Data throughput
$S_{effective}$	Adaptive ALOHA protocol controlled by the modified logistic function
R	Transmitted packets rate
ω	Vehicular connectivity total time
λ	Modified driver response time to modified channel communication time ratio
γ	Modified machine time to modified channel communication time ratio
$T_{auto\&conn.}$	Total time for autonomous and connected vehicle.

throughput for both connected and connected and autonomous vehicles is presented. The work introduces various time variables related to sensors, electronics, communication and human response to enable better ALOHA based random access approach for vehicular connectivity.

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

3. Methodology

Vehicular environment results in challenges related to efficiency, effectiveness, and reliability of communication protocols. Traffic management and congestion control requires fast and efficient delivery of basic safety messages (BSMs) and other types of emergency messages. This requires that efficient communication channel sharing is achieved through effective utilization of the shared communication medium. Media access control (MAC) will enable better channel access. Improving efficiency of a MAC protocol will improve throughput per shared channel.

Vehicles are equipped with on-board units (OBUs) to enable inter-vehicle communication in VANETs, with single and multi-hop communication using unicast, multicast, and broadcast to other vehicles or to road side units (RSUs). Modelling and simulation of vehicular interaction will enable better communication channel design and implementation [51-52].

The considered parameters for modelling interaction in connected vehicles and in autonomous and connected vehicles are:

(1) Throughput: This function measures amount of data delivered to the vehicle OBU by BSM messages either through inter-vehicle communication (connected) or through inter and intra vehicle communication (autonomous & connected).

(2) Driver time ($T_d=T_{perception}+T_{reaction}$): This is the time duration from the moment the driver receives a message and realizes that there is a message to the time the driver takes an action regarding the information in that message.

(3) Machine time ($T_m=T_{TX}+T_{RX}$): The needed time for the vehicle electronics and control devices (OBU) to process received data.

(4) Communication time ($\boldsymbol{T_c}$): Communication channel time, which is affected by surroundings, routing, and the vehicular dynamic movements.

From these assumptions a mathematical model can be derived, which interconnects and correlates all these variables and their effect on throughput.

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

In the connected vehicular environment, the following time parameters are modified logistic function (LF), which results in a modified logistic function (MLF) time parameters to enable adaptive performance:

$$\boldsymbol{T_d = (T_r)\left(\frac{1}{1+exp-\left(\frac{T_r}{T_{r\,(thresh)}}\right)}\right) = \phi} \tag{1}$$

$$\boldsymbol{T_m = (T_p)\left(\frac{1}{1+exp-\left(\frac{T_p}{T_{p\,(thresh)}}\right)}\right) = \varphi} \tag{2}$$

$$\boldsymbol{T_c = T_{com}\left(\frac{1}{1+exp-\left(\frac{T_{com}}{T_{com\,(thresh)}}\right)}\right) = \theta} \tag{3}$$

$$\boldsymbol{S_{effective} = S\left(\frac{T_c}{T_{conn}}\right)} \tag{4}$$

Where; T_{conn} is given by Eq. (5).

$$\boldsymbol{T_{conn} = (T_d + T_m + T_c) = (\phi + \varphi + \theta)} \tag{5}$$

Using ALOHA throughput function, Eq. (4) can be re-written as in Eq. (6).

$$\boldsymbol{S_{effective} = RT_{conn}exp(-RT_{conn})\left(\frac{T_c}{T_{conn}}\right)} \tag{6}$$

Where;
R: Packet rate
α: optimization factor (in this case =3)

Substituting Eqs. (1) to (3) into Eq. (6) yields Eq. (7).

$$\boldsymbol{S_{effective} = R(\phi + \varphi + \theta)exp \\ (-R(\phi + \varphi + \theta))\left(\frac{\theta}{\phi+\varphi+\theta}\right)} \tag{7}$$

Eq. (7) can be re-written as in Eq. (8).

$$\boldsymbol{S_{effective} \\ = \left(\frac{R(\phi+\varphi+\theta)exp(-R(\phi+\varphi+\theta))}{\left(\frac{\phi}{\theta}+\frac{\varphi}{\theta}+1\right)}\right)} \tag{8}$$

Eq. (8) can be further simplified as in Eq. (9).

$$\boldsymbol{S_{effective_{(conn)}} = \left(\frac{\omega exp(-\omega)}{(\lambda+\gamma+1)}\right)} \tag{9}$$

The Numerator in Eq. (9) represent an adaptive variation of the known ALOHA protocol. T_c in Eqs. (7) and (8) has three components related to time, with the following dependency:

1. T_r Counter starts once processing of received message is completed.
2. T_p Counter starts once the communication process of receiving a message is completed.
3. T_{com} Counter starts once the processing of human response is completed.

From Eqs. (7) and (9), it is clear the presence of two critical balancing parameters covering both initial throughput and effective throughput:

$$\boldsymbol{\lambda = \left(\frac{\phi}{\theta}\right)} \tag{10}$$

$$\boldsymbol{\gamma = \left(\frac{\varphi}{\theta}\right)} \tag{11}$$

From the Eqs. (10), and (11), the following is observed:

Initial throughout is affected by the total time with three affecting time parameters:

a. Communication Time (Inter-vehicle).
b. Processing time (Intra-vehicle).
c. Human response time.

The processing time and communication time parameters can be computed within a low margin of error compared to the human response time (driver), which carries high level of uncertainty. Thus, under certain cognitive and psychological pressures, human response could be very long (lack of concentration, deep thinking of other things, distracted). So, the common timing element that affects effective throughput, which allows actions to be taken is the human response time as Eq. (9) will be reduced to Eq. (12).

$$\boldsymbol{S_{effective_{(conn)}} = \omega exp - (\omega)} \tag{12}$$

Eq. (12) indicates that an action in response to a connected vehicle communication will be affected mainly by the human response time, through affecting throughput back to the controlling systems of the vehicle.

The ratio in Eqs. (10) and (11) show effect of human response on the effective throughput and the need for subsequent actions to be taken to avoid problems. As, the human response time increase the ratio in both Eq. (10) and (11) starts to decrease and to approach zero, which when substituted in Eq. (9) will render the denominator to a value of one. However, if the response time of the driver is short, then the ratio in Eqs. (10) and (11) will depend on the dynamic interaction between the sensors, electronics, and communication systems, which will control effective throughput.

In the case of autonomous and connected vehicles, the throughput expression becomes as in Eq. (13).

$$S_{effective} = RT_{auto\&conn} exp(-RT_{auto\&conn}) \left(\frac{\left(\frac{1}{1+exp-\left(\frac{T_p}{T_{p\ (thresh)}}\right)} \right)}{\left(\frac{1}{1+exp-\left(\frac{T_p}{T_{p\ (thresh)}}\right)} \right) + \left(\frac{1}{1+exp-\left(\frac{T_{com}}{T_{com\ (thresh)}}\right)} \right)} \right) \quad (13)$$

Where;

$$T_{auto\&conn.} = \left(T_p + T_{com}\right) \quad (14)$$

Eq. (14) is simplified as in Eq. (15).

$$S_{effective} = R(\phi + \varphi) exp\left(-R(\phi + \varphi)\right) \left(\frac{\theta}{\theta + \varphi}\right) \quad (15)$$

Further manipulation of Eq. (15) will result in Eq. (16).

$$S_{effective(auto\&conn))} = \kappa exp(-\kappa) \left(\frac{1}{1+\frac{\varphi}{\theta}}\right) \quad (16)$$

Eq. (16) can be represented as in Eq. (17).

$$S_{effective_{(auto\&conn)}} = \kappa exp(-\kappa) \left(\frac{1}{1+\beta}\right) \quad (17)$$

The Eqs. (16) and (17) are independent of the human factor and dependent on two factors:

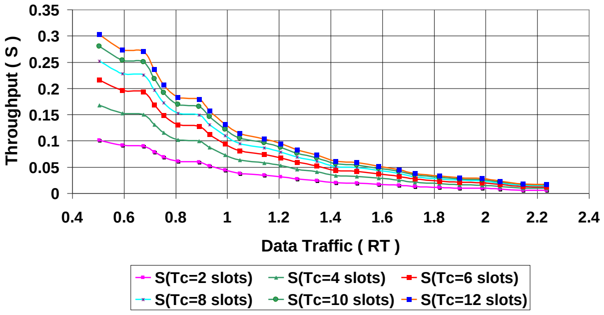

Figure. 1 Effect of communication time on throughput for connected vehicles as a function of data traffic.

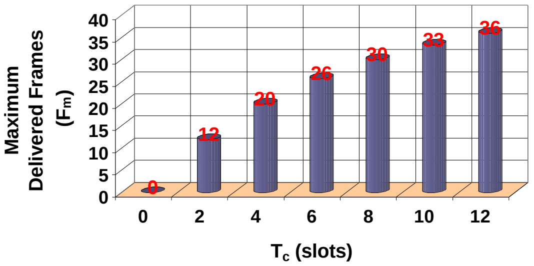

Figure. 2 Effect of communication time on maximum number of delivered frames for connected vehicles

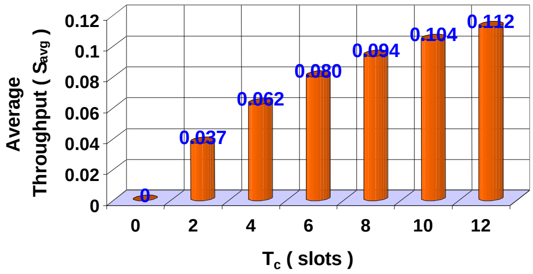

Figure. 3 Effect of communication time on average throughput for connected vehicles

1. The total value of the processing and communication times.
2. The ratio between the processing time and communication time.

As the communication time decreases or processing time increases, the denominator in equation (17) will converge to one, leaving Eq. (17) as in Eq. (18).

$$S_{effective_{(auto\&conn)}} = \kappa exp(-\kappa) \quad (18)$$

However, if the processing time increases significantly or the communication time decreases significantly (problem in the electronics or sensors or communication channels), then Eq. (18) will approach zero.

4. Results and discussion

4.1 Connected vehicles

4.1.1. Effect of communication time (T_c)

Figs. 1 to 3 present the simulated results, showing effect of communication time on throughput and delivered frames. The plots show an increase in throughput a function of increasing communication time. This is due to the fact that a stable and reliable communication channel is established for longer times, which enables more frames to be delivered. This also indicates lower rate of collision. The plots also show that as data traffic increase, throughput decreases, which is in agreement with both literature and logical expectations. This is a results of an increase probability of collision. It is also evident that the throughput for high T_c is high in amplitude as well.

This is an indication of efficient channel. It is aloes noticeable that as T_c approaching zero, throughput and delivered frames also approach zero.

4.1.2. Effect of machine time (T_m)

Figs. 4 to 6 present the simulated results, showing effect of machine time on throughput and delivered frames.

The plots show a decrease in throughput a function of incrementing machine time. This is due to the fact that a when sensors and electronics (including OBUs and RSUs) take long time to process exchanged data, other data cannot be exchanged, until the first set is processed. Thus the maximum number of delivered frames will be much less as shown. This process is independent of collision in the proposed model. In fact reducing the number of exchanged frames results in lower collision probability, but also reduce significantly the efficiency of the communication channel as proved in the plots.

4.1.3. Effect of driver time (T_d)

Figs. 7 to 9 present the simulated results, showing effect of driver time on throughput and delivered frames.

The plots show a decrease in throughput a function of incrementing driver time. This is due to the fact that a driver's response is much slower than electronics, sensors, and communication. Also, under different circumstances, the driver might be distracted to respond to received messages through the HMI. Thus the magnitude of throughput is the lowest among all cases. It is evident that as T_d approaches zero, maximum throughput and maximum number of delivered frames are reached.

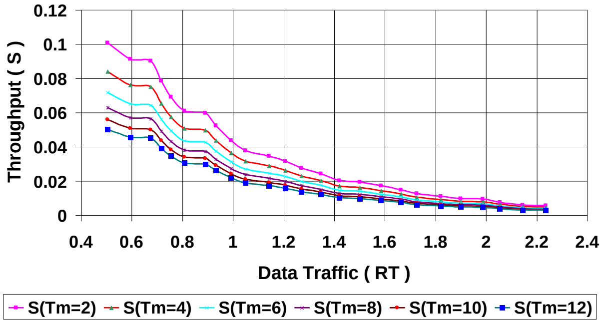

Figure. 4 Effect of machine time on throughput for connected vehicles

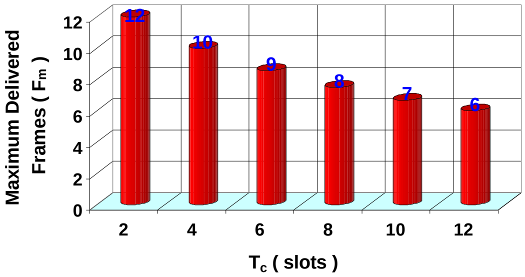

Figure. 5 Effect of machine time on maximum number of delivered frames for connected vehicles.

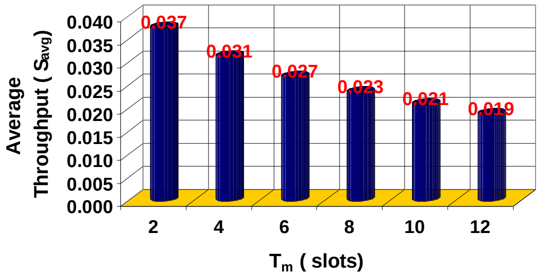

Figure. 6 Effect of machine time on average throughput for connected vehicles

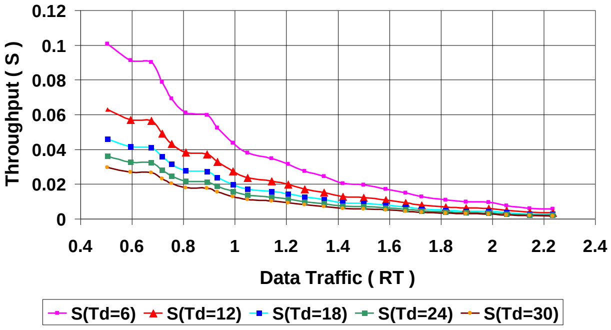

Figure. 7 Effect of driver time on throughput for connected vehicles

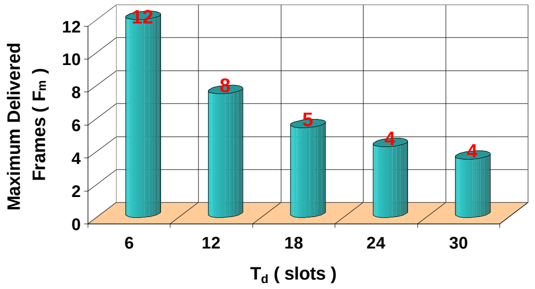

Figure. 8 Effect of driver time on maximum number of delivered frames for connected vehicles.

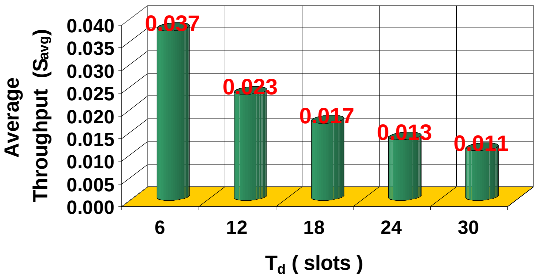

Figure. 9 Effect of driver time on average throughput for connected vehicles

4.2 Connected and autonomous vehicles

4.2.1. Effect of communication time (T_c)

Figs. 10 to 12 present the simulated results, showing effect of communication time on throughput and delivered frames.

The plots show a much larger increase in throughput a function of increasing communication time compared to the connected vehicles case. This is due to the fact that a stable and reliable communication channel is established for longer times, which enables more frames to be delivered, much higher than in the connected case, due to the absence of human interference and time for driver response (T_{driver}). This also reflected in the large number of frames that could be delivered. The plots also show that as data traffic increase, throughput decreases, with highest values at zero processing time (T_m).

4.2.2. Effect of machine time (T_m)

Figs. 13 to 15 present the simulated results, showing effect of machine time on throughput and delivered frames.

The plots show a decrease in throughput a function of incrementing machine time. However, it is evident in the case of connected and autonomous vehicles, that highest throughput and number of delivered frames occurs, when $T_{machine}$ =0. This is due to the absence of both human response and processing time parameters that adversely affect throughput and delivered frames.

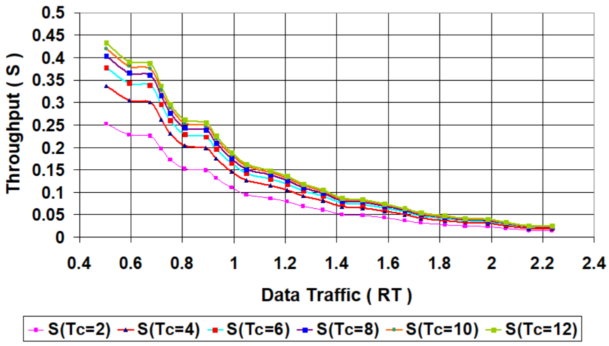

Figure. 10 Effect of communication time on throughput as a function of data traffic for autonomous & connected vehicles

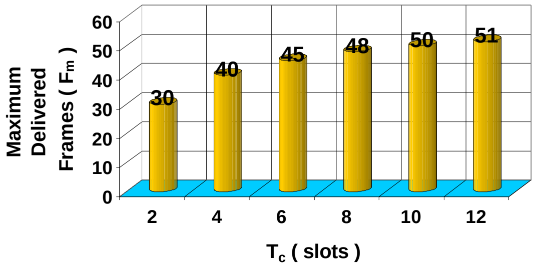

Figure. 11 Effect of communication time on maximum number of delivered frames for autonomous & connected vehicles

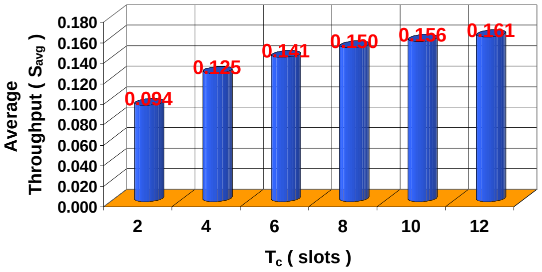

Figure. 12 Effect of communication time on average throughput for autonomous & connected vehicles

Figs. 16 and 17 present a comparison of averaged throughput over time slots as a function of both communication time and machine (processing) time. It is clear from the plots that autonomous and connected vehicles will suffer less during connectivity compared to only connect vehicles. This is a direct result of non-human participation with elimination of the driver response time

These observations and deductions based on the proposed mathematical model enables better utilization of the ALOHA algorithm due to the presence of the dynamic changing parameter that can be used for both connected and for autonomous and connected cases. To highlight that, Eq. (7) can be re-written as in Eq. (19).

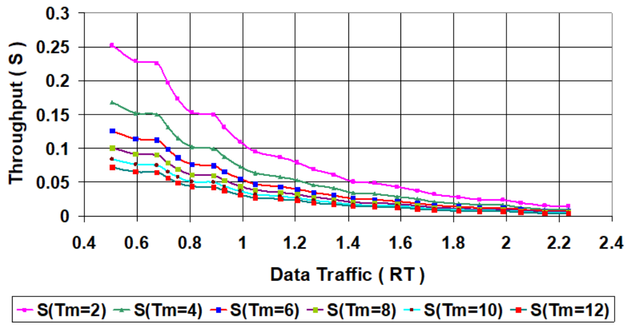

Figure. 13 Effect of machine time on throughput as a function of data traffic for autonomous & connected vehicles

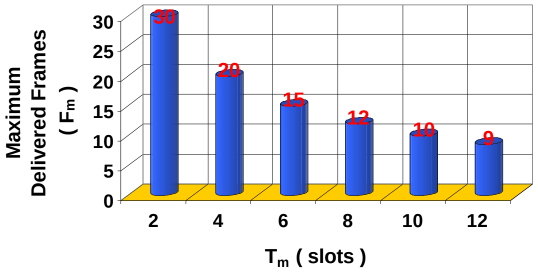

Figure. 14 Effect of machine time on maximum number of delivered frames for autonomous & connected vehicles.

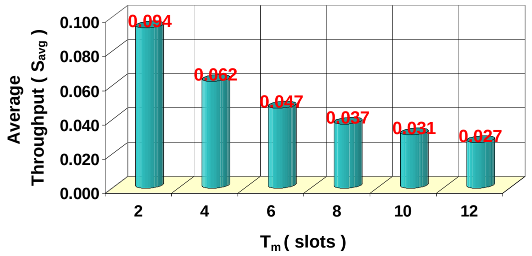

Figure. 15 Effect of machine time on average throughput for autonomous & connected vehicles

$$S_{\mathbf{effective}_{(\mathbf{conn})}} = \mathbf{R\zeta exp(-R\zeta)\Omega} \qquad (19)$$

Where;

$$\boldsymbol{\Omega = \left(\frac{\theta}{\phi+\varphi+\theta}\right) \quad and \quad \zeta = (\phi+\varphi+\theta)}$$

Also, Eq. (15) can be re-written as in equation (20).

$$\boldsymbol{S_{effective_{(auto\&conn)}} = R\varepsilon exp(-R\varepsilon)\lambda} \qquad (20)$$

Where;

$$\boldsymbol{\lambda = \left(\frac{\theta}{\theta+\varphi}\right) \quad , \ \varepsilon = (\theta+\varphi)}$$

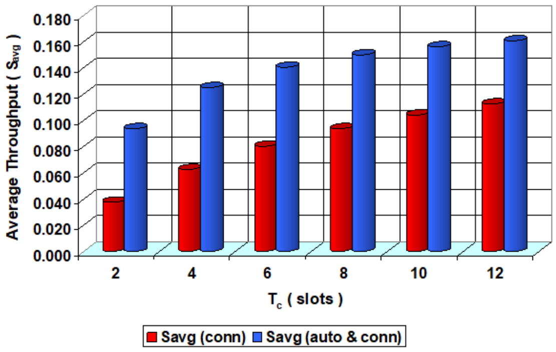

Figure. 16. Comparison between connected and autonomous & connected vehicles average throughout as a function of communication time

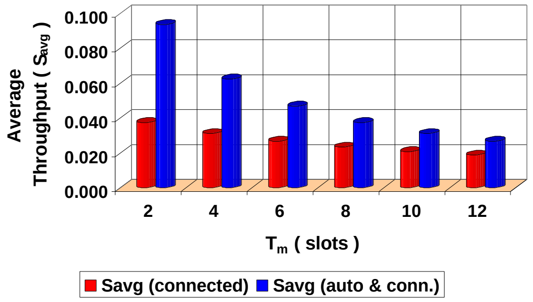

Figure. 17 Comparison between connected and autonomous & connected vehicles average throughout as a function of machine time

Thus, the throughput is modulated by the dynamically changing parameters in Eqs. (19) and (20).

5 Conclusions

The work achieved through mathematical modelling and simulation the following objectives:

1. Improvement of the conventional ALOHA protocol utilization in vehicular communication, by using adaptive and modified logistic function, which includes response time for drivers, electronics, sensors, and communication channel.
2. Modelling of the effect and contribution of response times to the efficiency of vehicular communication, which contributes to better Human-Machine Interface (HMI), communication networks design and application.
3. Modelling, simulation, analysis, and comparison between connected and autonomous and connected vehicles communication patterns.

4. Establishing the validity of using ALOHA in its modified form for vehicular communication, as it continuously carries out data transmission, but lacked initially to the intelligent and slot adaptive function.
5. Ability to correlated congestion and subsequent effects to the modification of ALOHA using time ratios.

The proposed and presented adaptive and dynamic approach, enables effective use and implementation of ALOHA algorithms with higher efficiency and effectiveness, as it provides adaptive slot times for data transmission and delivery. This is reflected through higher throughput and larger number of delivered frames.

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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