Driverless Cars with Communication System Based On Multiple Access Protocols

Tasneem A. Alani¹ and Salah A. Aliesawi¹

¹ College of Computer Science and Information Technology, University of Anbar, Ramadi

E-mail: totaahmed874@gmail.com

Abstract: Road traffic accidents are perceived as a serious problem in societies and one of the main reasons of fatalities, disability and injuries that inflict humans all over the world. Most of the Vehicular Ad Hoc Networks (VANETs) supported safety applications mainly rely on transmitting safety messages either by the means of vehicles or Road-Side Units (RSUs), whether it is a periodical action or in the case of an unexpected event, such as detecting unsafe road condition or a hard brake cases. This paper presents a Time Division Multiple Access (TDMA) protocol and Code Division Multiple Access (CDMA) protocol, which are designed specifically for supporting high-priority safety applications in a VANET scenario. The scenario of a virtual city is simulated and various metrics for performance are evaluated, comprising protocol overheads, good network mode, and channel usage, fairness of protocol, potential transmission collision, and delay delivery of the safety message. It was found that these protocols far outweighs the current Medium Access Control (MAC) schemes, which involve significant limitations in supporting the application of VANET. The suggested protocols can be seen as a promising tool for MAC in VANETs, which is able to achieve various unconventional safety applications to boost the standards of public safety and enhance safety for passengers, pedestrians and drivers on the roads. The result of the communication system is concluded that the approach provides optimum communication performance for received packets, packets delivery ratio, totally dropped packets and average end-to-end delay. The proposed scheme has a 94% packet delivery ratio in CDMA, 92% in TDMA and 82% than other cases.

Keywords: VANETs, RSU, Multiple Access Protocol, TDMA, CDMA.

1. Introduction

The world's road safety report 2015, that includes information from 180 nations in the world, specified that the overall number of deaths in the road accidents was 1.25 million yearly, while the mortality rates were considered to be maximum in the low-income developing nations [1]. The majority of accidents leading to death were because of children’s safety systems, motorcycle helmets, high-speed, safety belts and drunk driving, indicating that humans are the major cause of accidents [2]. Thus, there is a need for using a lot of technical approaches for controlling such causes and reducing them [3]. The most important challenges that faced the emergency response domain are traffic congestion and the delay in the arriving
of the emergency vehicles to the accident site. The emergency vehicles include police cars, fire trucks, or other more specialized vehicles.

The cars have evolved and improved very rapidly and become a large part of their functions working automatically [4]. All these aimed to protect people inside and outside the car [5]. The ideas of the driverless car appeared due to more than ten years ago and that the project Google 2009 was the first launch of those ideas [6]. In addition, the autonomous vehicles attempt on replacing humans through driving automation for the purpose of reducing the number of accidents on the roads due to human error [7]. Ad hoc networks are used via autonomous vehicles, in vehicular ad hoc networks (VANET) [8]. These networks allow more flexible and smart communication between vehicles in radio coverage area [9].

The rise of the driverless vehicles resulted in a growth in automotive technologies, due to its significant in developing novel concepts and environments to increase productivity and human conformability. A lot of solutions were suggested for offering adequate self driving vehicles environments with the ability of overcoming certain issues. In the case when self driving vehicles were equipped well, then the only aim was the way of controlling the external communication with the other vehicles along with updates appearing in the road and with the main center. Basic structure of communication infrastructure in self driving vehicles can be seen in Figure 1.

![Figure 1. Basic communication infrastructure of driverless vehicles [10].](image)

Figure 1 contains four RSUs, self driving vehicles and semi autonomous vehicles. These RSUs play significant role in providing sufficient radio signal, which help in exchange control data, notification and cooperative awareness messages as well as information. Communication system plays important role to deliver control data, important information and cooperative awareness messages from source node to destination node. However, data transmission is always travelling through what so called “channel”. In this case, fundamental problem of interference is raised spatially after the dramatic expansion of communication users. Thus, researchers have paid efforts for addressing this communication challenge. The concept of multiple access came into image to allow all users to share the radio resources without causing harmful effects to each other. These technologies are working at trade-off bases; in other word, at applications where large band is required with no concern to time. The available frequency is very limited to intake all spectrum users at once in the normal conditions; however, researches are conducted to study multiple access technologies as method to tackle the frequency deficiency. Such techniques are permitting users of spectrum to share the bands without congestion or interference.

This paper considers as a flexible communication system with the ability of communicating between the main center and moving license vehicles taking into account the problems in environments. In addition,
communication system design according to TDMA and CDMA approaches for being more secure and flexible. The suggested system was carried out via high-way environment concept for realizing high capacity, high quality of service, high security and robustness. The systems are tested with the number of metrics and measured parameters including packet delivery ration (PDR), end-to-end delay (E2E), etc. The rest of the paper is arranged as follows: Section 2 present the related works, Section 3 describes the proposed System, Section 4 explains the performance evaluation, Section 5 present the performance metrics, Section 6 present result and discussion and Section 7 present conclusion.

2. Related Works
In 2015, Mohamed Hadded, et al. provided the significance of utilizing collision free medium access control paradigm in the VANET, and after that showed a new topology based classification as well as providing a summary of the TDMA based MAC protocols, which were suggested for VANET. The study focused on the properties of such protocols, also their drawbacks and advantages. Lastly, providing qualitative comparisons, and discussing a few of the open issues which must be handled in future researches for the purpose of improving the performance related to the TDMA based MAC protocols with regard to V2V communications, [11]. In 2016, Nyoman W. Prasetya, et al. suggested clustered based TDMA through a traffic priority in the VANET. Also, the clustered traffic was specified as low and high traffic priority and embedded in the TDMA MAC Header, while the evaluation results are showing that the suggested method is performing better in high density of nodes, [12]. In 2017, Jiawei Huang, et al. designed a CTMAC, which is considered as a MAC protocol that is synthesizing the current approaches; including, arbitral reserving channel (utilized in TDMA based protocols) as well as random accessing channel (utilized in CSMA style protocols). Also, the CTMAC is swiftly changing its approach based on the density of vehicle, while its performance was better in comparison to other modern protocols. It is evaluating the CTMAC with the use of at scale simulations, the results of their work specified that the CTMAC is reducing channel completion time as well as increasing the goodput of network by 45% for a lot of network settings and application workloads, [13]. In 2018, Khattab M. Ali Alheeti, et al. proposed external communication system of autonomous vehicles that utilises CDMA scheme to improve its communication performance, to reach high capacity, high quality of service, high security, robustness and overcoming the obstacles in TDMA. The significant contribution in this paper is enabled autonomous vehicles to exchange essential information and control data between vehicles and RSU in that radio converge area. It enables vehicles to communicate in waste communication cases, such as, low bandwidth, accident and jamming, [10]. In 2018, Khattab M. Ali Alheeti, et al. suggested system for intrusion detection for protecting the communication systems regarding self driving cars; combine hierarchical models on the basis of log parameters and cluster developed for detecting Sybil and Wormhole attacks in the high-way usage situations. It is according to clusters, utilizing TDMA for overcoming a few of the problems of VANET including high mobility and density, also limitations of bandwidth to exchange messages, each one of the vehicle logs is calculating and storing various parameter values following receiving cooperative awareness messages from the close vehicles, [14]. In 2018, VanDung Nguyen, et al. suggested a modified packet which is transmitted in TDMA period for the purpose of reducing the transmission overhead within hybrid TDMA/CSMA multi channel MAC protocol. In addition, the simulation results are showing that a MAC protocol with modified packet is supporting effective packet delivery ratio related to control packet in CCH. Furthermore, the study analyzed hybrid TDMA/CSMA multi channel MAC protocol with modified packets within saturated throughput situations on the service channels (SCHs), while the analysis results are showing that the number of neighbors has insignificant impact on the establishment regarding the number of time slots in the TDMA periods as well as on the SCH within saturated throughput situations, [15].
3. The Proposed System
The proposed systems apply TDMA and CDMA for optimizing the connection among vehicles and RSU, minimizing the losing packets and decreasing trip time of vehicle. Both Figure 2 and Figure 3 show this approach conducted in three diverse protocols. Each component is in charge of performing its special tasks and to communicate with other components for transmitting/receiving information when needed.

Figure 2. Structure of proposed approach.

Both Figure 2 and 3 illustrate the structure of a high-scale interaction among three major components. Interactions between three: RSU and their massage format and vehicles for communication are shown on the right the map container.

3.1 Traffic Management Center (TMC) functionality
TMC is in charge of analyzing the traffic depending upon the information that was conveyed to the RSU. It also calculates the road measurement by the use of average travel time, occupancy window and intersecting roads delay factor. TMC also cleans up old information from the database to reduce RSUs’ query time, as shown in Figure 4.
Figure 4. TMC process flowchart.
3.2 Vehicle functionality

Each vehicle is responsible for calculating travel time for every section of the road that it has traveled and for transmitting it. Furthermore, route planning to determine the desired route shall be conducted separately by the On Board Unit (OBU) for each vehicle autonomously, as shown in Figure 5.

Figure 5. Vehicle application flowchart.

3.2.1 TDMA.

TDMA is a sophisticated technology for the reason that it requires a very careful synchronization between the transmitter and receiver. The digital mobile radio systems used in TDMA technology. A periodic frequency is assigned to individual mobile stations for special utilization only during a period. Moreover, in most situations, the entire system bandwidth is not allocated for a time slot period for one station, but the frequency of system is classified into sub-bands, and TDMA is utilized for various accesses to every
sub-band. A carrier frequency is known sub-bands, and the mobile system that utilizes the technology is called multiple carrier systems. TDMA-based MAC protocols have attracted mounting volume of the research network community. This class of protocols is utilized for managing channel access in various types of wireless networks, for example, global system for mobile communications (GSM), Ad hoc mobile networks, Ad hoc vehicle networks, wireless sensor networks, etc., as illustrated in Figure 6.

Figure 6. The concept of time division multiple access.

The benefits of using TDMA in MAC protocols are large and it is summarized as:
- For all vehicle nodes an equal access to the channel.
- Effective channel optimization with no collision.
- Communications being high reliable.
- Deterministic access time in spite of a severe traffic congestion.
- Quality of service for real-time application (RTA).

Algorithm 1. TDMA

| Input: A number of nodes N, TDMA schedule of n slots, each N(i) ∈ N is assigned equal number of slots S, where S = n/N, and each N(i) has a buffer B(i) |
| Output: Adaptive Sleep TDMA MAC |

FOR each N(i) ∈ N do the following
  WHILE TDMA round
    IF Ni(Si). start = true
      WHILE Ni(Si)
        IF node
          Ni.set(state) ← Active:
          IF Ni(Bi.numOutPkt) = 0
            Ni.set(state) ← idle:
            END IF
          ELSE
            Ni(Data_Packet.bufferfield) ← Bi.munOutPkt;
            Ni.send(Data_Packet): Ni.wait (Ack):
            IF Ack(Timer.timeout)
              Ni.set(state) ← sleep:
              END IF
            END EISE
            END IF
          END WHILE
        END IF
      END WHILE
    END IF
  END FOR
3.2.2 **CDMA**: It is a multi-vehicle technology with various codes. The same bandwidth is used in this approach for various vehicles. Every vehicle shall have its own spreading code assigned to it. To describe the CDMA, let consider the following example, the transmitted data is distributed on the spreading code of eight bits in both Vehicle 1 and Vehicle 2, so, it will be 16 bits as shown in Table 1. These two values are XORRed to generate the output of the transmitter. Bit zero is represented by +1 and bit one is represented by -1. At the transmitter side of vehicle1, the data bits to be transmitted is XORed with the spread code of Vehicle 1 and Vehicle 2 as shown in Figure 9. At the receiver side, the received bits will be XORed with the same spread code to generate the received data that is exactly the same of the transmitted data as shown in Figure 10.

**Table 1.** Spreading code for bits in CDMA.

| Transmitter | Vehicle 1 | Vehicle 2 |
|-------------|-----------|-----------|
| Data bit    | 0 1 1 0 0 1 1 1 | 0 0 1 1 0 0 0 0 |
| Data value  | +1 -1 +1 +1 -1 +1 +1 -1 | -1 +1 +1 +1 -1 +1 +1 +1 |
| Spread code | 1 1 0 1 0 1 0 1 | 0 0 1 0 1 0 0 0 |
| code value  | -1 +1 +1 -1 +1 -1 +1 +1 | +1 +1 +1 +1 -1 +1 +1 +1 |
| X-or bit    | 1 0 1 0 1 1 0 1 | 0 1 0 0 0 1 0 |
| X-or value  | -1 +1 -1 +1 -1 +1 -1 +1 | +1 +1 +1 +1 -1 +1 +1 +1 |

| Receiver | Vehicle 1 | Vehicle 2 |
|----------|-----------|-----------|
| Received bit | 1 0 1 0 1 0 0 1 | 0 0 1 0 0 0 1 0 |
| Received value | -1 +1 -1 +1 -1 +1 -1 +1 | +1 +1 +1 +1 -1 +1 +1 +1 |
| Spread code | 1 1 0 0 1 0 1 0 | 0 0 1 0 1 0 0 0 |
| Code value | -1 +1 -1 +1 -1 +1 -1 +1 | +1 +1 +1 +1 -1 +1 +1 +1 |
| X-or bit | 0 1 1 0 0 1 1 1 | 0 0 1 1 0 0 0 |
| X-or value | +1 -1 -1 +1 -1 -1 +1 -1 | +1 -1 +1 -1 +1 +1 +1 |

The structure considers 8 bits of spreading code; this leads to 256 separated users (vehicles) with unique code. All active users were sending their spreading data into the channel. These data will be summed to form the composite signal that transmitted to all users through the channel as shown in Figure 7. The sending data of the first channel (four bits) is spreaded into 32 bits according to the spreading code of 8 bits. The same thing is occurred for the other channels with their unique spreading code. All these spreading signals are summing to shape the composite signal to be transmitted in a channel.
On the other hand, the receiver structure is implemented to extract the original data signal of each channel as shown in Figure 8. The composite signal is received by the receiver, and then this signal is spreading by the unique spread code of the indicated channel. After that the channel bits are extracted, and then these values are compared. When the value is greater than zero, so it is represented by positive bit and when the value is less than zero, so it is represented by negative bit.

**Algorithm 2. CDMA**

**Input**: the vehicle sent signal to RSU

**Result**: For any particular directed edge e (v1, R), finding node set A, such that ∀v ∈ A, v can lead to v1, in n hops, by the use their outgoing edges if there is such an edge. Node set is similar to RSU group set here

- The two vehicle generate the signal (random zero and one with 16bit )
  - Vehicle1_data = random (16,1)
  - Vehicle2_data = random (16,1)
  Then convert the number to (-1,1)
- Generate spreadcode (random zero and one with 32 bit)
  - spreadcode = random (32,1)
  then convert to (-1,1)
- Modulation : by Caluclate the xor logic operation between vehicle data and spreadcode
  - Gold_pulse = spreadcode xor vehicle_data
- Demodulation : Caluclate the xor logic operation between glodcode and spreadcode
  - vehicle_data = spreadcode xor Gold_code
Figure 8. The receiver in CDMA.

3.3 Road-Side Unit (RSU) functionality
RSU is in charge of collecting travel time updates (ttu) from the vehicles and transferring updates to the TMC database. The transferred travel time in TMCare aggregated through transit RSU. Each RSU inquires about the segment of road metrics for which the RSU is in charge of and broadcasting them for vehicle use, as shown in Figure 9.

Figure 9. RSU application process flowchart.
4. Performance Evaluation

4.1 TDMA

The TDMA protocol allows multi-user to share the bandwidth by allocating different time slots. User transmit signals at intervals depending on multiplying the number of channels into time slots. In this work, the TDMA is applied to control collision between vehicles and provide vehicle routes. Achieved by vehicles starting moves on the road search for the nearest RSU unit and connection.

Figure 10. TDMA connecting two vehicles with the same RSU.

Figure 10 shows two vehicles connected using the same RSU. A random signal is generated in the analog form, then a sampling is done to convert the signal to the digital form (0,1). Then, the two signals embedded into TDMA, where slot1 from tdma follows the frame1 of the first signal, slot2 from tdma follows the frame1 of the second signal, slot3 from tdma follows the frame2 of the first signal, and slot4 of tdma follows the frame2 of the second signal, etc.

4.2 CDMA

CDMA is a concept where several transmitters send information at the same time over a single bandwidth communication channel. This protocol allows the sharing of frequency bands by interference between transmitters. Each CDMA transmitter has a unique code. In this work, the CDMA protocol is applied to build a connection between vehicles and RSU units to determine the route and minimize vehicle collisions. When each vehicle starts moving, it searches for the closest RSU unit to communicate with and exchange information, where the maximum connection range is 100 meters as shown in Figure 11. These two vehicles run on two roads and connected to RUS1, where the green color means the vehicle connects with RSU and red color means connectionless. The left side in the Figure 11 shows the transmitted and received signal in CDMA between the vehicle 1 and the RSU. The right side in the Figure 11 shows the transmitted and received signal in CDMA between the vehicle 2 and the RSU units.
Figure 11. The two vehicles connect to the RSU.

The two vehicles are continues moving until the distance between the vehicle1 and RSU1 unit reach more than 100 meter and lose the connection between them as shown in Figure 12. The right side shows there are no data translate and received between the vehicle1 and RUS units.

Figure 12. The vehicle1 loose the connection to the RUS unit.
5. Performance metrics

We have run sets of simulations with the scenario summarized in Table 2.

| Table 2. Summary of simulation properties. |
|-------------------------------------------|
| Number of edges for vehicles               | 2      |
| Total edge length for vehicles             | 50000 km |
| Number of RSUs                            | 6      |
| RSU query TMC at every                     | 4 sec  |

In this work, CDMA, TDMA and ad-hoc protocol are tested of autonomous and semi-autonomous vehicles to evaluate performance of the proposed protocol of communication system. It was validation under deferent communication case to approve performance communication system. The performance metrics communication is computed of vehicles in number cases under same communication condition. The performance metrics have been measured for same vehicle under TDMA and CDMA communication system with and without the proposed communication system. The six-performance metrics are described as following:

A. Transmission Packet: The total number sent packet from vehicle.

B. Received Packet: Number of routing packets receives at per RSU.

C. Packets Delivery Ratio: The ratio represents the number of packets received by the recipient in relation to the number of packets sent. The packets delivery ratio is calculated as:

\[
\text{Packet Delivery percentage} = \left(\frac{\text{Received Packet}}{\text{Transmission Packet}}\right) \times 100 \quad (1)
\]

D. Totally Dropped Packets: Represents the percentage of the number of packets lost in the system which are the packets sent but not received. totally dropped packets is calculated as:

\[
\text{Totally Dropped Packets} = (\text{Transmission Packet} - \text{Received Packet}) \quad (2)
\]

E. Average End-To-End Delay: It represents the average time for each packet sent by the sender until it is received by the recipient. The average end-to-end delay is calculated as:

\[
\text{Average End-To-End Delay} = (\text{Time at which packet received} - \text{Time at which packet Sent}) \quad (3)
\]

F. Number of Bit Error Rate: The total number bit dropped in each packet, at per RSU.

\[
\text{Number of error bit} = (\text{Number of byte of Totally Dropped Packets} \times 8) \quad (4)
\]

6. Results and Discussion

In Table 3, The active role of the proposed response system can be easily distinguishing in three cases of self-driving vehicles, in order to provide efficient functionality in protecting, increasing percentage of packet that transmit between sender/ received as well as protecting these types of vehicular networks. The proposed system can enhance transmission rate of autonomous and semi-autonomous vehicles by increase packet delivery rate in its external communications. It is mainly for dropping any request that target broadcasting packets.
Table 3. Performance Metrics of Normal Behavior.

| Performance Metrics       | Without TDMA & CDMA | TDMA       | CDMA       |
|---------------------------|---------------------|------------|------------|
| Transmission Packet       | 50000               | 50000      | 50000      |
| Received Packet           | 41368               | 46362      | 47308      |
| Packet Delivery Ratio     | 82.736%             | 92.7247%   | 94.617%    |
| Totally Dropped Packets   | 8632                | 3637.67    | 2691.5     |
| Average end to end Delay  | 72.6                | 37.026     | 36.3       |
| Number Of Bit Error Rate  | 138112              | 58202      | 43064      |

Figures (13 - 18), show the role of the CDMA and TDMA communication in providing slot time for each packet that are sent or received between vehicles in that zone. Where the Figure 13 shows the packet transmission in each state, where the amount of packet transmission are equal in all cases.

![Transmission Packet](image)

**Figure 13.** The Transmission Packet in each case.

Figure 14 shows received packet in each state, where the amount of Received packet in CDMA is higher than other cases.

![Received Packets](image)

**Figure 14.** The Received packet in each case.
Figure 15 shows Totally Dropped Packets in each state, where the Totally of Dropped Packets without TDMA& CDMA is higher than other cases.

![Totally Dropped Packets](image)

**Figure 15.** The Totally Dropped Packets in each case.

Figure 16 describes Packet Delivery Ratio in each state, where the Ratio of Packet Delivery without TDMA& CDMA is achieved 82% lower than other cases.

![Packet Delivery Ratio](image)

**Figure 16.** The Packet Delivery Ratio in each case.

Figure 17 shows Average end to end Delay in each state, where the Average end to end delay with CDMA is better than other cases.
Figure 17. The Average end to end Delay in each case.

Figure 18 shows the number of bit error rate in each state, where the amount of bit errors is high in first state.

Figure 18. The Number of Bit Error Rate in each case.

Figures (13 - 18) show performance metrics for CDMA and TDMA communication systems and reflect a vital role of the CDM & TDMA systems in improving the communication system of VANETs. It was evaluated under two various condition. The total number of generated packets is 5,0000 in two scenarios, the average number of received packets is 47,309p of VANETs with CDMA system and average drop 2691p. In addition, the average number of received packets is 41368p and average drop packets is 8632p in VANETs with regular communication system. However, the average number of received packets is 46362 p and average drop packets is 8632p in VANETs with TDMA communication system. Therefore, the researches can identify a vital role of the proposed communication system in external communication of self-driving vehicle.

7. Conclusions
In this work, different external communication systems for self-driving cars are used to support high-priority safety applications in a vehicular ad hoc network scenario. These two-multiple access TDMA and CDMA are investigated and compared using different scenarios and performance metrics where the communication system is conclude that the approach provides optimum communication performance for received packets, packets delivery ratio, totally dropped packets and average end to-end delay. The
The proposed scheme has a 94% packet delivery ratio in CDMA, 92% in TDMA and 82% than other cases. The simulation results in a virtual environment tested the movement of vehicles programmatically using GUI MATLAB package. The two techniques provide two different results, where CDMA provides a smaller transmission collision rate that lead to a significant rise in efficiency.

References

[1] L. W. Chen, Y. C. Tseng, and K. Z. Syue, “Surveillance on-the-road: Vehicular tracking and reporting by V2V communications,” *Comput. Networks*, vol. 67, pp. 154–163, 2014, doi: 10.1016/j.comnet.2014.03.031.

[2] J. A. F. F. Dias, J. J. P. C. Rodrigues, and L. Zhou, “Cooperation advances on vehicular communications: A survey,” *Veh. Commun.*, vol. 1, no. 1, pp. 22–32, 2014, doi: 10.1016/j.vehcom.2013.11.003.

[3] H. Z. Saif Al-Sultan, Moath M. Al-Doori, Ali H. Al-Bayatti, “A comprehensive survey on vehicular Ad Hoc network,” *Netw. Comput. Appl.*, vol. 37, pp. 380–392, 2014.

[4] S. R. Anand Paul, Naveen Chilamkurti, Alfred Daniel, *Intelligent vehicular communications*. 2017.

[5] A. A. Jorge Alfonso, José E. Naranjo, José M. Menéndez, *Vehicular Communications*. 2018.

[6] R. Florin and S. Olariu, “A survey of vehicular communications for traffic signal optimization,” *Veh. Commun.*, vol. 2, no. 2, pp. 70–79, 2015, doi: 10.1016/j.vehcom.2015.03.002.

[7] O. A. Wahab, H. Otrak, and A. Mourad, “VANET QoS-OLSR: QoS-based clustering protocol for Vehicular Ad hoc Networks,” *Comput. Commun.*, vol. 36, no. 13, pp. 1422–1435, 2013, doi: 10.1016/j.comcom.2013.07.003.

[8] S. Harrabi, W. Chainbi, and K. Ghedira, “A multi-agent approach for routing on vehicular Ad-Hoc networks,” *Procedia Comput. Sci.*, vol. 19, no. Ant, pp. 578–585, 2013, doi: 10.1016/j.procs.2013.06.077.

[9] Z. Naor, “Fast and reliable handoff for vehicular networks,” *Ad Hoc Networks*, vol. 11, no. 7, pp. 2136–2145, 2013, doi: 10.1016/j.adhoc.2012.05.002.

[10] K. M. Ali Alheeti, A. M. Awad, and M. S. Al-Ani, “An efficient approach of external communication system in autonomous vehicles based on CDMA,” *J. Theor. Appl. Inf. Technol.*, vol. 97, no. 3, pp. 764–774, 2019.

[11] M. Hadded, P. Muhlethaler, A. Laouiti, R. Zagrouba, and L. A. Saidane, “TDMA-Based MAC Protocols for Vehicular Ad Hoc Networks: A Survey, Qualitative Analysis, and Open Research Issues,” *IEEE Commun. Surv. Tutorials*, vol. 17, no. 4, pp. 2461–2492, 2015, doi: 10.1109/COMST.2015.2440374.

[12] N. W. Prasetya, T.-L. Sheu, A. Basuki, and M. A. Muslim, “Pre-Emptive Traffic Management for a Cluster-Based TDMA System in Vehicular Communications,” *J. Comput. Commun.*, vol. 05, no. 01, pp. 31–52, 2017, doi: 10.4236/jcc.2017.51004.

[13] J. Huang et al., “Synthesizing existing CSMA and TDMA based MAC protocols for VANETs,” *Sensors (Switzerland)*, vol. 17, no. 2, pp. 1–17, 2017, doi: 10.3390/s17020338.

[14] K. M. Ali Alheeti, M. S. Al-Ani, and K. McDonald-Maier, “A hierarchical detection method in external communication for self-driving vehicles based on TDMA,” *PLoS One*, vol. 13, no. 1, pp. 1–19, 2018, doi: 10.1371/journal.pone.0188760.

[15] V. Nguyen, T. A. Khoa, T. Z. Oo, N. H. Tran, C. S. Hong, and E. N. Huh, “Time slot utilization for efficient multi-channel MAC protocol in VANETs,” *Sensors (Switzerland)*, vol. 18, no. 9, pp. 1–19, 2018, doi: 10.3390/s18093028.