New Scheduling Scheme in Cellular V2X Communication

Wahida Ali Mansouri
Department of Computer Science and Information Technology, Faculty of Sciences and Arts, Northern Border University, Saudi Arabia | LETI laboratory, University of Sfax, Tunisia
wahida.smari@nbu.edu.sa (corresponding author)

Somia Asklany
Department of Computer Science and Information Technology, Faculty of Sciences and Arts, Northern Border University, Saudi Arabia | Modern Academy for Science and Technology, Egypt
somia.asklany@nbu.edu.sa

Salwa Hamda Othman
Department of Computer Science and Information Technology, Faculty of Sciences and Arts, Northern Border University, Saudi Arabia | LETI laboratory, University of Sfax, Tunisia
salwa.othmen@nbu.edu.sa

Abdulbasit A. Darem
Department of Computer Science, College of Science, Northern Border University, Saudi Arabia
basit.darem@nbu.edu.sa

Received: 16 March 2024 | Revised: 1 April 2024 | Accepted: 2 April 2024

ABSTRACT

The enormous increase in mobile data traffic and the heterogeneity and stringent Quality of Service (QoS) requirements of different applications have placed a substantial strain on the underlying network infrastructure and represent a challenge for Cellular Vehicle-to-Everything (Cellular V2X). V2X communication is a key enabler for the realization of smart and connected transportation systems, offering a wide range of applications, such as enhanced road safety, traffic management, and autonomous driving. In this context, the best way to provide great flexibility and address both the present and future QoS concerns is to use intelligent Radio Resource Management (RRM) in general and creative packet scheduling in particular. The diverse QoS requirements of multiple application classes under dynamic network conditions present substantial challenges for conventional scheduling algorithms given the increasing demand for bandwidth-hungry applications. This study proposes a scheduling system for V2X communications based on traffic prioritization that manages QoS provisioning for different types of traffic considering channel quality, remaining payload, and delay. Simulation results demonstrate the highly promising performance of the proposed New Scheduling V2X Communications (NSVC) algorithm that leads to significantly lower latencies, as the average delay scheme did not exceed 0.001 ms for 100 users.

Keywords-QoS; V2X communications; scheduling; traffic prioritization

I. INTRODUCTION

Technological advances offer intelligent devices and innovative services and applications that make daily life easier. The need for communication services increases as new applications and technologies are developed. The massive expansion of services and applications requires more efficient networks with higher data rates, lower latencies, greater spectrum efficiency, and increased network capacity [1-2]. 5G communication networks address this significant growth in services and applications. The 5G communication system follows the technical path taken by the 4th Generation (4G) wireless technologies and makes new advancements in several crucial technical areas. Higher-order modulation and orthogonal frequency division multiplexing transmission technologies are still used in 5G networks. Several recent studies have focused on 5G networks, the possible challenges it entails, and the techniques followed for energy efficiency [15-16]. Vehicle-to-Everything (V2X) communication and 5G are two closely related technologies that are poised to transform the future of transportation and connectivity. V2X communication is an essential component of modern Intelligent

Transportation Systems (ITS), which enables vehicles to exchange information with other vehicles, infrastructure, and road users. V2X communication encompasses various communication scenarios, including Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Pedestrian (V2P), and Vehicle-to-Network (V2N) interactions. These interactions allow vehicles to exchange information regarding the traffic condition, road hazards, collision warnings, and multimedia content. By allowing vehicles and infrastructure to communicate and share critical information, V2X can mitigate accidents, reduce congestion, improve the environment, and pave the way for a safer and more efficient future of transportation [3].

The emergence of V2X communications has brought new challenges and opportunities to the field of scheduling algorithms. These advanced scheduling techniques are crucial to effectively manage the limited frequency spectrum while meeting the unique requirements of V2X communications. An overview of V2X communications and the 3rd Generation Partnership Project (3GPP) was presented in [4]. This study analyzed 3GPP's contributions to support advanced C-V2X applications, focusing on their evolution of standards and underlying concepts. In [2], the general aspects of V2X applications were discussed without delving into a comprehensive overview that includes all aspects of these applications. Efficient scheduling of V2X messages is crucial to ensure timely and reliable data transmission, improving road safety, traffic management, and overall transportation efficiency. Recent advances demonstrate how fuzzy logic is used in machine learning. In [5], a self-adaptive fuzzy logic-based strategy was developed to allocate resources intelligently and reasonably. This method considered factors of timing, interference, and priority. In [6], a Fuzzy Inference System (FIS) was proposed having two inputs, distance and Channel State Information (CSI), to determine the suitable probability P_{rk}. However, this resource management algorithm did not consider other vital parameters that affect decision-making, such as packet priority and delay. In [7], a conflict-free centralized method was developed on cellular V2X for Mode 3 scheduled resource allocation. This study proceeded with the protocol interference model, whereas the proposed methods were applied to networks where physical modeling of interference is feasible but did not consider the priority factor of V2X messages.

In [8], a scheduling technique was proposed to ensure reliable V2V communication, employing slow varying CSI and offering an additional margin of Signal-to-Interference-plus-Noise Ratio (SINR) for V2V links. This technique addressed V2V sidelink Radio Resource Management (RRM) for CAD use cases. In [9], a scheduling algorithm was presented to optimize resource allocation in next-generation 5G networks and maximize system throughput, accommodate a larger number of users, ensure fairness in resource allocation, and minimize error rates. In [17], the focus was on addressing the issue of autonomously controlling transmission power in D2D communication. In [10], a resource allocation and scheduling algorithm was presented for V2X communications, specifically focused on Device-to-Device (D2D) communication between Cellular User Equipment (C-UE) and Vehicular User Equipment (V-UE). This algorithm was designed to address several key objectives, including maximizing the sum rate, ensuring fairness for C-UEs, and guaranteeing reliability and low latency for V-UEs.

This study proposes a new dynamic scheduling called New Scheduling V2X Communications (NSVC) based on priority assignment that gives priority to messages related to collision warnings, emergency braking, and other critical safety applications. This scheduling method is designed based on traffic prioritization, latency, and channel conditions. The proposed scheduling scheme leverages the flexibility and scalability of cellular networks to dynamically assign priority to V2X messages, optimizing the use of available bandwidth, while ensuring low latency and high reliability. This study presents a comprehensive analysis of the key components of the proposed scheme, entailing the QoS parameters considered and the prioritization techniques. Furthermore, this paper evaluates the performance of the proposed scheduling scheme based on several parameters, comparing it with the existing PSA [13] and Earliest Deadline First (EDF) approaches in terms of latency, average blocking rate, and packet loss ratio. The results show significant improvements in communication reliability and latency reduction, which makes the proposed method suitable for safety-critical V2X applications.

II. SYSTEM MODEL

This study considered a V2X network with a single eNodeB and several vehicles denoted by N. In this context, NT_x and NR_x represent the total number of transmitters and receivers, respectively. It was assumed that the V2X infrastructure within the cell is randomly distributed, to cover a wide range of distances within the cell. Additionally, minimal variations in vehicle speeds were assumed to ensure system stability, and the available bandwidth was divided into K subchannels to ensure data transmission.

A. V2X Services Classification

V2X communications demand real-time capabilities and place a significant emphasis on reliability. V2X messages are classified into two categories according to their importance and urgency. The first class is called Safety-traffic (C1), which refers to a specific category of messages that are primarily designed to improve road safety and mitigate the risk of accidents. These messages play a critical role in improving driver awareness, providing timely warnings, and facilitating cooperative behavior among vehicles. In this class, transmitted messages require a high level of QoS and immediate service delivery to mitigate road accidents. The second class presents the non-safety traffic. This type of service refers to messages that are not directly related to improving road safety or preventing accidents. These messages serve various purposes, such as providing drivers and passengers with information, entertainment, or convenience. The specific services do not have strict requirements on reliability and latency. Non-safety traffic can be further divided into two distinct classes: Management Traffic (C2) and Infotainment Traffic (C3). Although Management Traffic messages are not considered safety-critical, they demand prompt handling due to their significant impact on traffic management and efficiency. The objective of Management Traffic messages is to optimize traffic flow, minimize travel time, and alleviate traffic congestion. Infotainment Traffic presents connections that tolerate delay and provide comfort and convenience applications for users. The proposed algorithm assigns priority to these three categories (C1, C2, and C3) based on channel conditions, while ensuring that V-UEs with weaker channel conditions are not neglected or deprioritized. The incoming requests of vehicles are sorted in this module into different service classes as in Algorithm 1.

ALGORITHM 1. V2X SERVICES CLASSIFICATION

```
Begin
For j=1 : N vehicles
  If (request j is Safety-traffic)
    Insert request j into Safety-traffic class C1
  Else if (request j is Management Traffic)
    Insert request j into Management Traffic class (C2
  Else
    Insert request j into Infotainment Traffic class C3
  End if
End for
End
```

B. *SINR Modeling*

The eNB has the capability of estimating the CSI. The V2X links should be estimated at the V-UEs and then fed back to the eNB, and then use the uplink idle band to transmit the CSI report. The SINR received by R_x is expressed in [11] as follows:

$$SINR_{j,k} = \frac{P_J\,\rho_{j,m,k}}{1+\sum_{s\in S_{j,m,k}} P_s\,\rho_{s,m,k}} \tag{1}$$

where P_J is the transmit power of the transmitter T_x VU j per resource block, $S_{j,m,k}$ refers to the set of active vehicular users that induce interference when the resource block is used for the transmission by R_x VUE m on the subchannel k, and $\rho_{j,m,k}$ presents the SINR of the subchannel k between the links T_x (j) and R_x (m), which is expressed as follows:

$$\rho_{j,m,k} = \frac{|H_{j,m,k}|^2}{(n_m)^2} \tag{2}$$

where n_m CN(0, σ^2) is the Additive White Gaussian Noise (AWGN) for the receiver R_x VU(m), with the noise variance σ^2, $H_{j,m,k}$ is the coefficient of the channel, which can be expressed by a constant power gain factor introduced by the amplifier, and the antenna denoted by G, $h_{j,m,k}$ is the complex Gaussian variable CN(0,1) representing Rayleigh fading, β is the shadow fading, $d_{j,m}$ is the distance between VU(j) and (m) in the resource block, and α is the path loss exponent.

$$H_{j,m,k} = G * h_{j,m,k} * \beta(d_{j,m})^{-\alpha} \tag{3}$$

A weighted approach is implemented to assess different levels of channel quality. Therefore, the estimated SINR was compared with the required SINR and a predefined threshold value, denoted as γ. The weights $\theta_{j,k}$ for each channel state are determined as:

- Good Channel: If the estimated SINR exceeds the threshold, which indicates a favorable channel condition, a weight of 1 is assigned to $\theta_{j,k}$.
- Medium Channel: If the estimated SINR falls within the range between the threshold and the required SINR, the channel level is considered medium and a weight of 0.5 is assigned to $\theta_{j,k}$.
- Bad Channel: If the estimated SINR is lower than the required SINR, indicating poor channel quality, a weight of 0 is assigned to $\theta_{j,k}$.

The weight $\theta_{j,k}$ is expressed as follows:

$$\theta_{j,k} = \begin{cases} 1 & if\ SINR_{j,k} > \gamma \\ 0.5 & if\ \gamma > SINR_{j,k} \geq SINR_{j,k,req} \\ 0 & if\ SINR_{j,k} < \gamma \end{cases} \tag{4}$$

By employing these weight assignments based on channel conditions, the current state of VUE j into the priority index can be effectively incorporated, allowing for differentiated treatment of varying channel states.

C. *Latency Modeling*

Latency stands as a critical performance metric, given that achieving low-latency communication is imperative to ensure the safety and effectiveness of V2X applications, especially in time-sensitive situations, such as autonomous driving and collision avoidance. Different latency components are associated with transmission, routing, and processing. Regarding the conventional cellular network architecture, a focus was given to modeling the one-way messaging latency as follows:

$$L_{one-way} = L_{UL} + L_{Net} + L_{PRO} \tag{5}$$

where L_{UL} is the radio transmission latency in the Uplink (UL), L_{PRO} is the message processing latency, and L_{Net} is the network latency expressed as:

$$L_{Net} = L_{BH} + L_{TN} + L_{CN} \tag{6}$$

where L_{BH} presents the latency in the Backhaul (BH) network, L_{TN} is the latency in the Transport Network (TN), and L_{CN} is the Core Network (CN) latency. As in [12], the required deadline (End-to-End latency (L_{E2E})) can be expressed as:

$$L_{E2E} = L_{UL} + 2\,L_{Net} + L_{PRO} + L_{DL} \tag{7}$$

where L_{DL} is the Downlink (DL) transmission latency.

D. *Priority Index*

To assign a priority index to each packet, the remaining time before its deadline expires is determined as follows:

$$\delta^n_{c,j} = L_{E2E,j,c} - D_{HOL,j} \tag{8}$$

where $L_{E2E,j,c}$ represents the required deadline of the user j packet belonging to class c, and $D_{HOL,j}$ denotes the Head-of-Line (HOL) delay for the first packet within the buffer of the j^{th} user. Therefore, $D_{HOL,j}$ signifies the duration for which a packet has remained in the queue since its generation. Then, the priority index $P^n_{c,j}$ of packet n is calculated as follows:

$$P^n_{c,j} = max\left(0, \frac{1}{\left(\delta^n_{c,j} * \Delta_{left,j}\right)} * \theta_{j,k}\right) \tag{9}$$

where $\Delta_{left,j}$ is the remaining HOL packet size of the user j, and $\theta_{j,k}$ is the weight that reflects the current channel state. Both the remaining HOL packet size $\Delta_{left,j}$ and the remaining time before the deadline $\delta_{c,j}^{n}$ are of equal importance in terms of the metric calculation. The maximum of 0 and the calculated metric are selected to prevent negative values, which could cause starvation of UEs in high-load scenarios.

Consequently, the proposed scheduling scheme gives preference to time-sensitive and low-volume data traffic and good channel conditions compared to either time-tolerant or high-volume data traffic types. In this manner, NSVC enables an efficient scheduling algorithm that meets all the necessary requirements.

III. PROPOSED SYSTEM

Designing a scheduling algorithm for V2X requires considering various factors, including latency and traffic conditions. The proposed algorithm aims to prioritize and schedule V2X messages based on channel conditions, delay, and volume of data traffic. The suggested scheduling algorithm classifies the incoming V2X messages into three different categories according to their importance and urgency. (Algorithm 1), calculates the SINR, and determines channel quality. Then it assigns priorities to each message category. The scheduler is equipped with two queues, S (Service) and B (Bad channel quality. Upon the packet's arrival, its priority index is computed and subsequently added to the service queue S. Only if the channel condition is predicted to be good, is the packet transmitted. Otherwise, it defers its transmission and places the packet in a first-come-first-served queue B.

ALGORITHM 2. SCHEDULING SCHEME

```
Begin
For each arrival packet n of vehicle j, perform steps 1-7
  calculate $\delta_{c,j}^{n}$ the earliest expiry time before $L_{E2E,j,c}$
    expires (Eq. 8),
  calculate $\mathrm{SINR}_{j,k}$
  determine the weights $\theta_{j,k}$
  calculate the priority index $P_{c,j}^{n}$ of packet $n$ (Eq. 9)
  if the channel quality is good or medium then schedule
    the packet with the highest priority (head of queue S)
  else store the packet identifier in the queue B
  end if
  check the end-to-end deadline, such packets are then
    dropped
end for
end
```

IV. PERFORMANCE EVALUATION

A simulation model was used to evaluate the performance of the proposed scheduling algorithm. A V2X communication network, which consists of a single cell with a radius equal to 1.5 km, a system bandwidth of 10MHz, and one eNB carrier frequency of 2 GHz, was simulated. The VUEs were considered to move in a freeway scenario. The data arrival process from the vehicle to the eNB link is a Poisson process. The service time of packets is assumed to follow exponential distributions. In this study, three V2X classes were considered: Safety Traffic, Management traffic, and Infotainment Traffic. For safety-related services, the maximum acceptable end-to-end latency must not exceed 100ms [12]. Table I portrays the fundamental parameters used for the analysis and simulation, based on the parameters utilized in [14].

TABLE I. SIMULATION PARAMETERS

Parameter	Value
System bandwidth	10 MHz
Number of eNodeB	1
Power of each T_x user on each k channel	[20, 23db]
SINR threshold of V-UEs	5 dB
Shadow fading standard deviation	9 dB
Noise power σ^2	-114 dbm
Thermal Noise Power Spectral N0	174dBm/Hz
V -UEs speed	Random (5, 150) km/h
Duration of TTI	1 ms
Number of VUEs	10-100

A comparative performance evaluation of the proposed NSVC scheme was performed against the Earliest Deadline First (EDF) and PSA [13] algorithms. The primary focus is to compare the performance of three scheduling algorithms, EDF, PSA, and NSVC. The EDF considers only the time remaining until a deadline, whereas NSVC considers the remaining time to the deadline, the remaining payload size for data transmission, and the channel quality. The performance of the algorithms was evaluated deploying three key metrics. The first metric is the blocking ratio, which assesses the ability to handle connection requests due to network congestion or lack of resources. The second metric is the packet loss ratio, which is the ratio of the number of lost packets to the total number of packets sent. The third metric is the average packet waiting time, which is calculated as the ratio of the total waiting time of packets to the total number of packets. Figure 1 depicts the blocking probability, which illustrates the ability to ensure timely and reliable communication for safety-critical requests, such as a command from an autonomous vehicle or an emergency service signal. The blocking ratio values of the proposed NSVC algorithm are lower than EDF and PSA. The proposed NSVC experienced a low blocking probability for the safety-traffic class because it is capable of handling critical communication requests promptly and without disruption by prioritizing the safety-critical messages. Thus, high blocking probabilities can be unacceptable in safety-critical scenarios, as they can lead to delays or even failures in critical communications, potentially endangering lives or disrupting vital services. The proposed NVSC algorithm did not exceed 2.5% when the active VUEs in the cell were equal to 100.

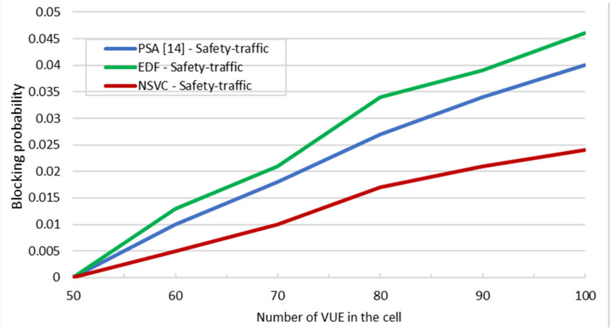

Fig. 1. Blocking Probability for the Safety-Traffic class.

Figure 2 demonstrates how the blocking probability varies according to the number of active users for Management Traffic and Infotainment Traffic. With a small number of users, the blocking probability is initially low. This might mean that the network has sufficient resources to accommodate the incoming traffic requests without much congestion or blocking. As the number of users on the network increases, the blocking probability gradually increases. Even with an increase to 100 users, the blocking probability for Management Traffic did not exceed 4% in the NSVC algorithm, as it gives priority to Safety Traffic, then to Management Traffic, and then to Infotainment Traffic.

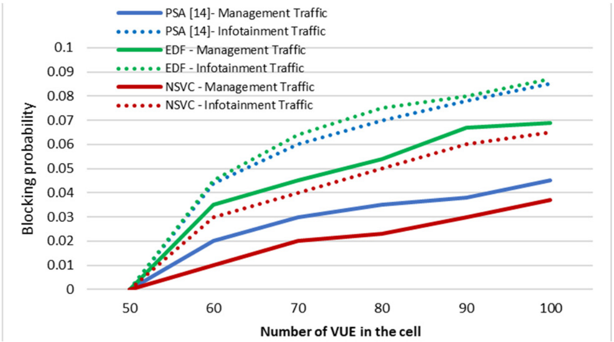

Fig. 2. Blocking Probability for the Management and Infotainment Traffic classes.

As displayed in Figure 3, initially, with a low number of VUEs (50 users), the network handles Safety Traffic with minimal packet loss. However, as the number of VUEs increases, the packet loss increases, as not all Safety Traffic packets can be transmitted within their deadlines. However, compared to EDF and PSA, the proposed NSVC scheduling scheme has the best values (minimum values of 1.4% for 100 users compared to EDF and PSA, which reach 2.4% and 2%, respectively).

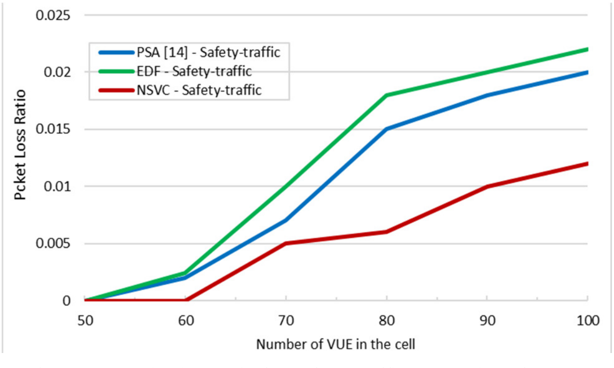

Fig. 3. Packet loss ratio for Safety Traffic vs. number of VUEs.

Figure 4 exhibits the average waiting time for Safety Traffic. The results clearly indicate that the average waiting experienced by Safety Traffic is within the tolerable threshold. These results show that the proposed NSVC scheduling algorithm met the stringent V2X application delay requirements. The average waiting time increased but still meets the requirement of end-to-end delay. The average delay did not exceed 0.001 ms for 100 users. This value was exceeded by the EDF and PSA algorithms. This reveals that the proposed algorithm serves more packets before their deadlines expire, particularly for packets that benefit from favorable channel quality. Consequently, packets from users enjoying excellent channel quality are assigned higher priority compared to those from users with medium or bad channel quality.

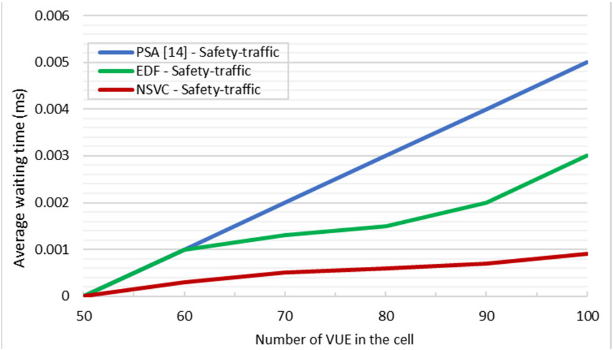

Fig. 4. Average waiting time for Safety Traffic vs. number of VUEs.

V. CONCLUSION

This study designed and implemented a scheduling scheme-based prioritization of safety messages to optimize QoS among V2X communications. The proposed scheduling algorithm uses different metrics to assign priority to each message and mitigates the instantaneous fluctuation of the SNIR. Prioritization of the user's request was based on channel quality, end-to-end latency, and remaining payload to improve fairness among the users. This study makes several significant contributions to V2X communication by introducing a novel and effective solution for dynamic scheduling that adapts dynamically to changing network conditions and traffic demands. Through extensive simulations and evaluations, the efficiency of the proposed NSVC algorithm was demonstrated in improving latency, reliability, and throughput, particularly in scenarios with varying traffic loads and network conditions. The results disclosed that the proposed scheduling algorithm guarantees satisfactory QoS and outperforms other algorithms. NSVC leads to significantly lower latencies. Artificial intelligence and machine learning can play a significant role in improving cellular V2X systems by processing and analyzing massive amounts of data generated by connected vehicles and infrastructure. Future work will employ machine learning in an enhanced scheduling scheme.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the approval and support of this research study by grant no. CSAT-2022-11-1641 from the Deanship of Scientific Research, Northern Border University, Arar, KSA.

REFERENCES

[1] M. J. Khan, M. A. Khan, A. Beg, S. Malik, and H. El-Sayed, "An overview of the 3GPP identified Use Cases for V2X Services," *Procedia Computer Science*, vol. 198, pp. 750–756, Jan. 2022, https://doi.org/10.1016/j.procs.2021.12.317.

[2] M. Harounabadi, D. M. Soleymani, S. Bhadauria, M. Leyh, and E. Roth-Mandutz, "V2X in 3GPP Standardization: NR Sidelink in Release-16 and Beyond," *IEEE Communications Standards Magazine*, vol. 5, no. 1, pp. 12–21, Mar. 2021, https://doi.org/10.1109/MCOMSTD.001.2000070.

[3] I. Soto, M. Calderon, O. Amador, and M. Urueña, "A survey on road safety and traffic efficiency vehicular applications based on C-V2X technologies," *Vehicular Communications*, vol. 33, Jan. 2022, Art. no. 100428, https://doi.org/10.1016/j.vehcom.2021.100428.

[4] M. J. Khan *et al.*, "Advancing C-V2X for Level 5 Autonomous Driving from the Perspective of 3GPP Standards," *Sensors*, vol. 23, no. 4, Jan. 2023, Art. no. 2261, https://doi.org/10.3390/s23042261.

[5] M. Zhang, Y. Dou, P. H. J. Chong, H. C. B. Chan, and B.-C. Seet, "Fuzzy Logic-Based Resource Allocation Algorithm for V2X Communications in 5G Cellular Networks," *IEEE Journal on Selected Areas in Communications*, vol. 39, no. 8, pp. 2501–2513, Dec. 2021, https://doi.org/10.1109/JSAC.2021.3087244.

[6] T. I. Bayu, Y. F. Huang, and J. K. Chen, "Performance of Fuzzy Inference System for Adaptive Resource Allocation in C-V2X Networks," *Electronics*, vol. 11, no. 23, 2022, https://doi.org/10.3390/electronics11234063.

[7] Z. Naghsh and S. Valaee, "Conflict-Free Scheduling in Cellular V2X Communications," *IEEE/ACM Transactions on Networking*, vol. 29, no. 1, pp. 106–119, Oct. 2021, https://doi.org/10.1109/TNET.2020.3030850.

[8] P. Keshavamurthy, E. Pateromichelakis, D. Dahlhaus, and C. Zhou, "Resource Scheduling for V2V Communications in Co-Operative Automated Driving," in *2020 IEEE Wireless Communications and Networking Conference (WCNC)*, Seoul, Korea (South), May 2020, pp. 1–6, https://doi.org/10.1109/WCNC45663.2020.9120846.

[9] E. Bouhamed, H. Marouane, A. Trabelsi, and F. Zerai, "Scheduling Algorithm supporting V2X Communications based on NOMA access," *IFAC-PapersOnLine*, vol. 53, no. 2, pp. 14948–14953, Jan. 2020, https://doi.org/10.1016/j.ifacol.2020.12.1984.

[10] A. Masmoudi, S. Feki, K. Mnif, and F. Zarai, "Efficient Scheduling and Resource Allocation for D2D-based LTE-V2X Communications," in *2019 15th International Wireless Communications & Mobile Computing Conference (IWCMC)*, Tangier, Morocco, Jun. 2019, pp. 496–501, https://doi.org/10.1109/IWCMC.2019.8766682.

[11] B. Di, L. Song, Y. Li, and G. Y. Li, "NOMA-Based Low-Latency and High-Reliable Broadcast Communications for 5G V2X Services," in *GLOBECOM 2017 - 2017 IEEE Global Communications Conference*, Singapore, Dec. 2017, https://doi.org/10.1109/GLOCOM.2017.8254830.

[12] S. A. M. Ali and E. H. Al-Hemairy, "Minimizing E2E Delay in V2X over Cellular Networks: Review and Challenges," *Iraqi Journal of Information and communication Technology*, vol. 2, no. 4, 2019.

[13] A. D. Trabelsi, H. Marouane, and F. Zarai, "Priority-based Scheduling Algorithm for NOMA-integrated V2X," *Advances in Science, Technology and Engineering Systems Journal*, vol. 5, no. 6, pp. 1225–1236, Dec. 2020, https://doi.org/10.25046/aj0506146.

[14] A. Kanavos, D. Fragkos, and A. Kaloxylos, "V2X Communication over Cellular Networks: Capabilities and Challenges," *Telecom*, vol. 2, no. 1, pp. 1–26, Mar. 2021, https://doi.org/10.3390/telecom2010001.

[15] H. H. Alshortan, A. Alogla, M. a. H. Eleiwa, and M. I. Khan, "Low Cost High Gain 8×8 Planar Array Antenna for 5G Applications at 28GHz," *Engineering, Technology & Applied Science Research*, vol. 11, no. 6, pp. 7964–7967, Dec. 2021, https://doi.org/10.48084/etasr.4609.

[16] M. Azhar and A. Shabbir, "5G Networks: Challenges and Techniques for Energy Efficiency," *Engineering, Technology & Applied Science Research*, vol. 8, no. 2, pp. 2864–2868, Apr. 2018, https://doi.org/10.48084/etasr.1623.

[17] S. Alotaibi, "Interference Mitigation Strategy for D2D Communication in 5G Networks," *Engineering, Technology & Applied Science Research*, vol. 13, no. 4, pp. 11318–11325, Aug. 2023, https://doi.org/10.48084/etasr.6008.