Uluslararası İleri Doğa Bilimleri ve Mühendislik Araştırmaları Dergisi
Sayı 8, S. 274-283, 2, 2024

Araştırma Makalesi

International Journal of Advanced Natural Sciences and Engineering Researches
Volume 8, pp. 274-283, 2, 2024

Research Article

https://as-proceeding.com/index.php/ijanser
ISSN: 2980-0811

Recent Advances in Controller Area Network (CAN) Bus Technology of Autonomous Vehicle (AV)

Zeina Ali, Qutaiba I. Ali

Electronics Engineering College Ninevah University, University of Mosul Mosul, Iraq
Engineering College University of Mosul Mosul, Iraq

qut1974@gmail.com

(Received: 05 March 2024, Accepted: 08 March 2024)

(4th International Conference on Innovative Academic Studies ICIAS 2024, March 12-13, 2024)

ATIF/REFERENCE: Ali, Z. & Ali, Q. I. (2024). Recent Advances in Controller Area Network (CAN) Bus Technology of Autonomous Vehicle (AV). *International Journal of Advanced Natural Sciences and Engineering Researches, 8(2), 274-283.*

Abstract: The development of autonomous vehicles (AVs) has gained significant attention in recent years due to their increased safety, reduced traffic congestion, and improved energy efficiency. Controller Area Network (CAN) bus protocols in AVs are the most common type of internal vehicle networks (INVs) necessary for proper vehicle operation. This paper summarizes previous works, including state of the art regarding wired and wireless CAN bus types. In addition to, this work exploring future trends regarding this bus and its implementation.

Keywords- CAN, Autonomous Vehicle (AV) , Wireless CAN

I. INTRODUCTION

As AV testing, research, and application increase, standardized regulations and guidelines are required to guarantee their secure integration into society. NHTSA and the United States Department of Transportation have both adhered to the SAE automation standard. Automated vehicles are categorised into six levels [1]. Level 5 vehicles have absolute authority over all driving functions, whereas Level 0 vehicles are entirely under the control of the driver. Illustrate the levels in Fig.1. Levels 2 and 3 are utilized by commercial vehicles such as Tesla Autopilot [2], GM Cruise [3], and BMW [4]. Lane keeping assist, adaptive cruise control, and automatic braking are all features of autonomous vehicles.

While there may be slight variations among different vehicle systems, they all must address the issue of autonomous navigation, which can be broadly categorized into four key components: perception, localization and mapping, path planning, and control. Perception involves the utilization of a set of sensors installed on the vehicle to detect, understand, and interpret the surrounding environment. This includes identifying both stationary and moving obstacles, such as other vehicles, pedestrians, traffic signals, road signs, and curbs. The objective of localization and mapping tasks is to precisely determine the global position of the vehicle in relation to world coordinates.

In addition, their responsibility includes constructing a comprehensive representation of the vehicle's environment and consistently monitoring the vehicle's position in relation to that representation. Path planning utilizes the results of the preceding two tasks to determine the most advantageous and secure route for the AV to reach its destination, taking into account all potential road obstacles [5]. Finally, the control element produces the required values of acceleration, torque, and steering angle for the vehicle to track the chosen path [6]. In addition, several studies examine the incorporation of connected vehicle technologies [7,8], such as vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) technologies. These technologies enable the sharing of crucial information to establish an improved cooperative driving environment, as depicted in Fig. 2 This enhanced and refined collaborative perception enables vehicles to efficiently forecast the actions of crucial environmental elements (such as obstacles, roads, ego-vehicles, environment, and driver behavior) and proactively anticipate any potentially dangerous occurrences.

The networking and communication technologies in AV can be classified into two categories: intra-vehicle and inter-vehicle. The intravehicular network serves as a basis for achieving autonomous driving by connecting the electronic components within the vehicle. Another crucial component is the inter-vehicle network, which serves as the means for vehicles to communicate and exchange information with other vehicles.[9]

The inter-vehicle network is categorized into low-power technologies such as ZigBee or Bluetooth, 802.11 family technologies, base station-driven technologies, and other auxiliary technologies. Zigbee DSRC and LTE-V are specifically tailored for automotive applications. Emerging communication technologies, such as 5G, computing technologies, SWIPT, VLC, and deep learning, offer new opportunities for networking and communications in autonomous driving.[9]

Conversely, intravehicular network facilitating the flow of status data and control signals among an AV's sensors, actuators, and ECUs. These technologies establish a scalable backbone infrastructure, which is integral for implementing sophisticated functions like sensory perception, motion control, and system fault diagnostics in a unified central system[10]. AVs currently employ a range of data bus technologies, including Ethernet, Local Interconnect Network (LIN), FlexRay, Media Oriented System Transport (MOST), and CAN bus.

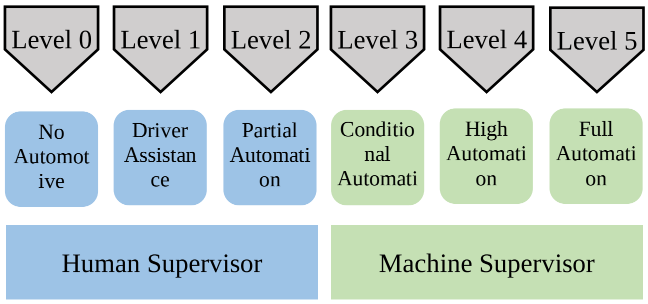

Fig. 1. SAE's six AV levels

Controller Area Network (CAN) is the most popular intra vehicle networking (IVN) technology [11][12]. It appears in a variety of functional domains, including powertrain, body and comfort, and multimedia (to send control messages). CAN is a multimaster serial bus that uses Carrier Sense Multiple Access with Bitwise Arbitration (CSMA/BA) to access a shared channel. Each CAN message has a maximum payload of 8 bytes and begins with an Arbitration field containing the message identifier (11 bits in CAN 2.0A, 29 in CAN 2.0B). The Identifier field determines the message's priority. If multiple messages are transmitted at the same time, an arbitration phase begins. At the end of this phase, the highest priority message continues unaffected, while the others are stopped. CAN supports several speeds, including 125 Kbps, 250 Kbps, 500 Kbps, and up to 1 Mbps. For in-car use, the typical maximum CAN speed is 500 Kbps. To identify permanent failures, CAN provides error detection and recovery mechanisms, as well as fault confinement mechanisms.

CAN FD [13] improves on traditional CAN by allowing for longer payloads (0-8, 12, 16, 20, 24, 32, 48, and 64 bytes) and faster transmission speeds (2 Mbps, 5 Mbps). The longer payload reduces the need for long message segmentation while also adding security features. CAN FD controllers also support Classical CAN frames, which means they can send and receive both classical and CAN FD frames. Both protocols (Classical CAN and CAN FD) are specified in ISO 11898-1:2015.Fig. 3 illustrates the arbitration process on a CAN bus, showcasing three nodes attempting to transmit data simultaneously[14][15].

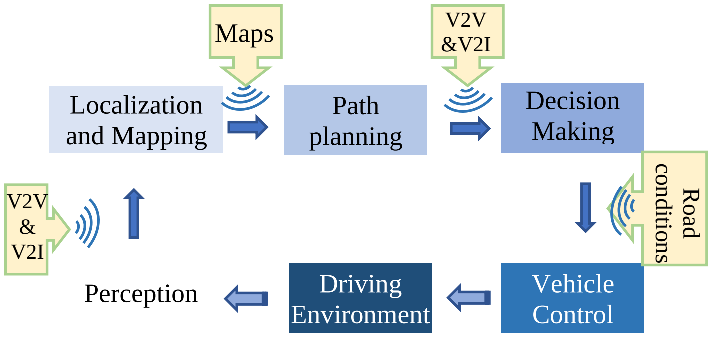

Fig. 2: Full autonomous navigation system. Senser Technology, fusion overview, V2V and V2I

Since Bosch introduced the CAN bus, it has undergone many studies in various fields, such as measuring performance, representing the vehicle's internal ECUs, expanding the capabilities of the bus, alleviating as much as possible the wiring problems, convergence between the increase of the vehicle's ECUs and the capabilities of bus, and other fields, in different research areas related to this bus.

This research paper summarizes the latest previous work in this field, divided into two parts: Wired CAN and Wireless CAN bus, each divided into other sub-parts. The contribution of this research work is on how current research efforts on CAN performance reliability can solve the problems and complexities involved in autonomous vehicles. The remainder of this article follows: Section II covers previous work on the wired CAN bus. Section III will expand on most previous works on the wireless CAN bus. Challenges and open issues in section IV. Finally, Section V presents the conclusions and concluding remarks. Fig.3 shows the taxonomy of CAN bus-related works

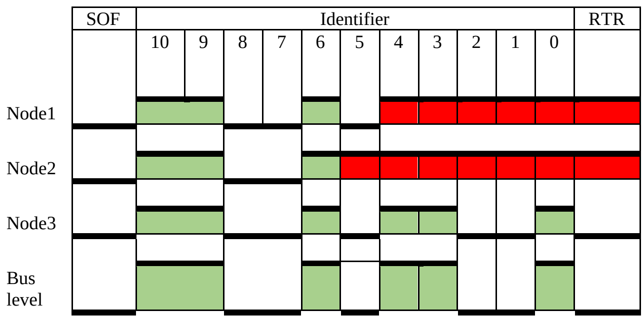

Fig. 3 Arbitration process on CAN bus

II. Recent Advance in Wired CAN bus

The literature on wired CAN bus can be categorized into two distinct groups. The first topic relates to evaluating the efficiency of a CAN bus. The second topic focuses on connecting a CAN bus with other IVNs through a gateway or comparing the performance of a CAN bus with other IVNs.
Regarding measuring the performance of the CAN bus, the authors of [16] investigated CAN-FD-8-byte and CAN networks. In the simulation network, four ECUs engage in the exchange of over 40 messages. CAN-FD demonstrated higher efficiency compared to CAN in terms of network message busload and worst-case response time (WCRT). Utilizing CANoe (CAN Open Environment) for simulation purposes.

The authors of [17] determined the CAN and CAN FD bus transmission times for a network consisting of two ECUs, one of which was responsible for transmitting data and the other for receiving it. Messages and data bytes were correlated. CAN FD demonstrated superior performance compared to CAN when flashing large amounts of data to the ECU. Simulation through the use of CANoe.

The authors of [18] investigated a CAN FD network that transmitted an SAE benchmark message set based on time and events. In MATLAB simulations, the CAN FD protocol improves real-time control system message delay and bus utilization. the authors of [19] utilized FSAE standards to assess the busload and response time of four electric vehicle ECUs that connected using classical CAN . The simulation was conducted using CANoe with hardware.

In the same context, the authors of [20] utilized J1939 and International Organization for Standardization (ISO) 11783 to simulate and analyze a network for an agricultural machine vehicle. The network performance of CAN and CAN FD was compared, specifically for data sizes of 8 and 64 bytes. The simulated network consisted of three ECUs and a virtual terminal. The CAN with Flexible Data-Rate (CAN FD) exhibits reduced busload, lower Worst-Case Response Time (WCRT), and decreased jitter compared to the traditional CAN protocol. These findings were observed during a simulation conducted using CANoe software. the authors of [21] utilized queuing analysis to develop analytical models for CAN, CAN-FD, and Automotive Ethernet, which allowed them to estimate response time. The 81-

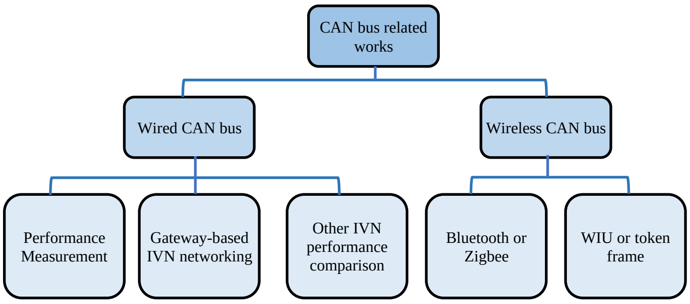

Fig. 4 Taxonomy of CAN bus-related works

message CAN bus interconnects six ECUs using both CAN and CAN FD protocols. These connections are simulated using OMNET++.

In the second topic thar focuses on connecting a CAN bus with other IVNs through a gateway , the authors of [22] created three communication protocols, namely LIN, classical CAN, and FlexRay, along with a gateway protocol for message transfer between them. Utilizing CANoe for Hardware Simulation. the authors of [23] examined the impact of CAN bus architecture on transmission efficiency. The simulation of the multi-level-bus CAN network with a gateway resulted in a reduction of busload and message delay. The simulation was conducted using CANoe.

Regarding to performance comparison CAN with other IVN, the authors of [24] compared the busload of four ECUs in ring and star network topologies. The star topology exhibited superior performance compared to the ring topology. Utilizing CANoe for simulation purposes. the authors of [25] conducted a comparison of the latency between FlexRay and CAN-Bus. The CAN-Bus protocol is more suitable for real-time systems, while FlexRay is well-suited for low-priority deterministic data transfer, the simulation is performed by hardware using HSC12 microcontrollers.

The authors of [26] analyzed the performance of the Classical CAN network. When comparing classical CAN+LIN to CAN, CAN has an average transmission speed that is 2.7% faster.Utilizing CANoe for simulation purposes. the authors of [27] conducted a simulation and test of the autonomous emergency braking system by integrating a commercial radar sensor with the CAN bus. It provided them with the ability to regulate the velocity of the self-driving vehicle and monitor its trajectory. They measured the inconsistency in the initial braking position and the distance required to come to a complete stop. Table 1 provided in this study summarizes the relevant papers that propose the examination and modeling of the CAN bus.

TABLE 1 :Summary Of Existing Potential Studies On Wired CAN Bus

Ref	Application	Research Tool	Contribution And Strength
[16]	General Application	CANoe	CAN-FD-8-byte and CAN networks were examined. Four ECUs exchange more than 40 messages in the simulation network. CAN-FD outperformed CAN for network message busload and WCRT.
[17]	Network Automotive	CANoe	The authors measured CAN and CAN FD bus transmission times for a network of two ECUs, one sending and one receiving data. Data bytes and messages were correlated. CAN FD outperformed CAN when flashing large amounts of data to the ECU.
[18]	Industrial Applications	MATLAB	A CAN FD network that sent time- and event-based SAE benchmark message set was examined. The CAN FD protocol improves real-time control system message delay and bus utilization in simulations.
[19]	Electric Vehicle	CANoe, Hardware	FSAE standards were used to measure busload and response time for four electric vehicle ECUs.
[20]	Agriculture Machine	CANoe	J1939 and ISO 11783 were used to simulate and analyze an agricultural machine vehicle network. They compared CAN and CAN FD network performance (8 and 64 bytes). Three ECUs and a virtual terminal comprised the simulated network. CAN FD had lower busload, WCRT, and jitter than CAN.
[21]	Vehicle	OMNeT++	Queuing analysis-based CAN, CAN-FD, and Automotive Ethernet analytical models estimated response time. The 81-message CAN bus connects six ECUs in CAN and CAN FD.
[22]	Vehicle	CANoe, Hardware	The authors created three communication protocols LIN, classical CAN, and FlexRay and a gateway protocol to transfer messages between them.
[23]	Vehicle	CANoe	The authors investigated how CAN bus structure affects transmission performance. The multi-level-bus CAN network with a gateway reduced busload and message delay in simulations.
[24]	Vehicle	CANoe	Ring and star network topologies were compared by busload for four ECUs. The star topology outperformed the ring topology.
[25]	Vehicle	HCS12 microcontrollers	The authors compared FlexRay and CAN-Bus latency. CAN-Bus is better for hard-time systems, and FlexRay is good for low-priority deterministic data transfer.
[26]	Vehicle	CANoe	Classical CAN network performance was analyzed. Compared to classical CAN+LIN, CAN has a 2.7% faster average transmission speed.
[27]	AV	Commercial radar	The authors simulated and tested the emergency braking system by connecting the sensor of a radar to the CAN bus. It allowed them to control the speed of the AV and track its movement. They measured the braking starting position error and braking distance.

III. RECENT ADVANCE IN WIRELESS CAN BUS

This section is divided into two parts, the first part explores the closest related works in the field of implement Wireless CAN network using Bluetooth or Zigbee technology. The second part of literatures highlights the closest related works that dealt with Wireless Interworking Unit (WIU) or WCAN network token frame. While the last part holds the other wireless communications (i.e., gateway or bridge) .

In the context of Bluetooth technology, the authors of [28] discussed the use of Bluetooth modules for reliable communication in vehicles. However, the latency of these networks, ranging from 10ms to 47ms, is a significant issue, particularly for critical applications like engine control. The authors argue that CAN to Bluetooth gateways is not suitable for high-speed wireless networks due to high processing delays. They propose a solution to reduce latencies, focusing on the processing delay, which is the major contributing factor to overall latency. Instead of converting raw data from sensors/ECUs to CAN frames and vice versa, raw data can be collected and framed in Bluetooth packets.

The authors of [29] proposes using Bluetooth Low Energy (BLE) within a Vehicular Ad Hoc Network to enable low-cost and energy-efficient communication between sensor nodes and the ECU. For both stationary and moving scenarios, the proposed BLE-based system demonstrated high packet delivery success rates, with average RSSI values of at least -10dBm. Extensive testing revealed that a system based on the BLE chipset CC2540/CC2541 could significantly reduce the battery's current draw, extending its runtime. the authors of [30] proposed a wireless gateway for trucks and trailers with detachable drivers' cabins. The gateway, consisting of two transceivers, forwards information from each transceiver's CAN network to a common wireless link using Bluetooth CAN bridge.

In the context of Zigbee, the authors of [31] employs the implementation of a Wireless Controller Area Network (WCAN) for CAN message exchange, it proposes a CAN message-based protocol in a wireless setting, utilizing Zigbee protocol . This research includes developing a WCAN on the FlexDevel board. The system's effectiveness for real-time control is affirmed using the 53 CAN messages of SEA benchmark. the authors of [32] designed a new protocol called Hybrid-Backpressure Collection Protocol (Hybrid-BCP) to collect data from intra-car sensors. It is backward-compatible with CAN bus technology and builds on the BCP protocol for wireless sensor networks.

The protocol is tested on CAN and ZigBee transceivers, demonstrating load balancing and routing functionalities. Simulation results show Hybrid-BCP outperforms tree-based data collection protocols by 12% in throughput and maintains high packet delivery rate and low packet delay for safety-critical sensors. Three sensors are used for simulation. the authors of [33] designed a WCAN protocol for communication between the smart NOx (nitrogen oxide) sensor on diesel engines and the engine control ECU using ZigBee (IEEE 802.15.4) technology using XBee module. A MATLAB Simulink module is programmed into the ECM ECU to receive the data, calculate O2% and NOx ppm values, and display the results on a monitor connected to the ECM ECU. The results compared were with Wi-Fi, LoRa, BLE.

In the other hand, an implementation of a CAN/IEEE 802.11b WLAN/CAN interworking system using a WIU has been proposed in literature [34][35][36][37]. The system aims to extend CAN segments by utilizing an IEEE 802.11b WLAN via WIU. The authors of [34][36][37] extend the size of the distributed area of CAN networks and enable the CAN networks to communicate with other LANs by designing a WIU that is capable of connecting remote CAN 2.0A nodes over IEEE 802.11b WLAN using the encapsulation method.

The authors of [35] proposed a solution to interconnect CAN segments using a wireless MAN based on the IEEE 802.16 standard as a backbone system. The proposed solution described a model for an internetworking unit that integrates the traffic generated by CAN segments into IEEE 802.16 wireless MAN using an encapsulation technique.

Regarding the use of the WCAN network token frame method, which allows nodes to share a common broadcast channel by taking turns sending their frames. This is achieved through the use of a token frame that circulates around the network for a specified period of time. The authors of [38] present a WCAN that employs a token ring protocol to reduce collisions and ensure efficient communication.

This method, based on tokens, enables nodes to transmit data sequentially, resulting in anticipated enhancements in network latency and packet delivery. The study evaluates the efficiency of WCAN by conducting a simulation in the QualNet platform, with a specific emphasis on the possibility of enhancing data transfer rate and minimizing delay in wireless communications, particularly for WCAN.

In the context, the authors of [39] developed a WCAN using the Wireless Token Ring Protocol (WTRP) for a network of 20 nodes. They employed a MAC protocol specifically designed for wireless networks to minimize the need for retransmissions caused by collisions. The token frame method is employed to facilitate channel access for nodes, enabling them to share a shared broadcast channel. WCAN undergoes testing using QualNet and is compared to IEEE 802.11 in ring networks, demonstrating superior performance in the test results.

TABLE 2: SUMMARY OF EXISTING POTENTIAL STUDIES ON WIRELESS CAN BUS

Ref	Application	wireless Technology	Contribution And Strength
[28]	Vehicle	Bluetooth	Developed a gateway to convert CAN messages to Bluetooth format using the CANBLUE module.
[29]	Vehicle	Bluetooth	Utilized BLE for cost-effective and energy-efficient communication between sensor nodes and the ECU.
[30]	Trucks and Trailers	Bluetooth	Implemented a wireless CAN bridge integrated with the AddVolt network for vehicular refrigeration systems.
[31]	Real-time control applications	ZigBee	Enable CAN message exchange wirelessly by developing WCAN on FlexDevel board.
[32]	Vehicle	ZigBee	Designed the Hybrid-Backpressure Collection Protocol to enhance intra-car sensor data collection.
[33]	Heavy-Duty Vehicles	ZigBee	Created a WCAN protocol to link NOx sensors with the vehicle's engine control unit.
[34]	Industrial control applications	IEEE 802.11 WLAN	Extend CAN segments by utilizing IEEE 802.11 WLAN via WIU
[39]	General	802.11b Token Ring	Implemented a Wireless CAN (WCAN) based on the wireless token ring protocol for multiple nodes.
[40]	Industrial	On-off Keying	Developed a simple wireless transceiver that is compatible with CAN controllers.
[41]	Vehicle	bridge	Designed and validated the CAN-to-RF platform connected to real cluster units to generate speed and RPM data.
[43]	Vehicle	Relay	The ViCAN is a hybrid communication architecture designed. It combines wireless and wired CAN to reduce wiring complexity and seamless manner.

The authors of [40] created a simple wireless transceiver to simulate three nodes. The transmitter node has channel access every 100 ms to transmit data frames. It uses Carrier Sense Multiple Access / Non-Destructive Arbitration (CSMA/NDA) protocols with On-Off Keying (OOK) modulation to represent dominant and recessive bits of the CAN bus. The transmitter and receiver used Amplitude shift keying (ASK) at a carrier frequency of 433 MHz and a bit rate of 20 kbps.

The authors of [41] designed a simple point to point wireless communication which bridges remote CAN buses, it used CAN-to-RF platform prototype to simulate seven nodes with a varying packet transmission interval with STM32F103RC Cortex-M3 microcontroller and the TI CC2500 radio, the channel characteristics of the 2.4 GHz.

The authors of [42] suggested Vehicular wireless CAN (ViCAN) is a two-hop network that requires communication bits to travel via both wired and wireless media. ViCAN relays connect the two. The wired connection is assumed to be error-free. Wireless peripherals and ViCAN relays are separated by several wavelengths that are resulting in wireless channels that are mutually independent. OOK modulation is used by the wireless transmitter.

The authors of [43] Implemented the WCAN, which consists of three hardware components: a pedal with an integrated body controller as the gateway, a cluster unit, and a digital tachometer, and connects between them using a wireless platform consisting of an ACM Cortex-M3 microcontroller with a TI CC2520 low-power radio. This platform supports direct wired connections to a local CAN unit. **Table 2** summarizes the related works in the field of wireless CAN networking.

IV. Challenges and Open Issues

Previous studies on wired Controller Area Networks (CAN) primarily focused on simulating a restricted set of vehicle electronic control units and a limited number of messages. Most studies did not replicate external electronic control units or compare the performance of a conventional bus with a CAN-FD bus.

On the other hand, related to wireless CAN buses, specific tasks pertaining to wireless technology have been dependent on Bluetooth or ZigBee. The speed limitations of these technologies, coupled with the restricted number of simulated nodes, render them unsuitable for high-speed vehicular wireless networks. Other works need to address the issues of reducing interference, and they need to address the challenges of scalability and complexity constraints in anti-jamming.

V. Conclusions

This paper has investigated CAN technologies in autonomous driving to promote the perception and planning abilities of existing autonomous vehicles relying on sensors. Some relevant literature and concepts are proposed explicitly for autonomous vehicles, which are more complicated and have more interactive information; we have come up with lots of CAN technologies that are suitable for or have been used in autonomous vehicles. We have carried out a retrospective and forward-looking study on the CAN bus in autonomous driving; it dealt with two main aspects: the wireless CAN and the modern trend represented by wireless. Finally, we have summarized the challenges and open issues, which are convenient for researchers to refer to and carry out further studies. Anyhow, networking and communications for autonomous driving, especially the CAN bus, still have a long way to go and require the joint efforts of academia and industry.

References

[1] SAE International. "Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles." SAE Int. 4970, no. 724 (2018): 1-5. [online]. Available: https://www.sae.org/standards/content/j3016_202104/

[2] Autopilot. [online]. Available: https://www.tesla.com/autopilot

[3] Fayyad, Jamil, Mohammad A. Jaradat, Dominique Gruyer, and Homayoun Najjaran. "Deep learning sensor fusion for autonomous vehicle perception and localization: A review." Sensors 20, no. 15 (2020): 4220.

[4] BMW Group. "Bmw group, intel and mobileye team up to bring fully autonomous driving to streets by 2021." (2016).[online] Available: https://www.press.bmwgroup.com/global/article/detail/T0261586EN/bmw-group-intel-and-mobileye-team-up-to-bring-fully-autonomous-driving-to-streets-by-2021?language=en

[5] Katrakazas, Christos, Mohammed Quddus, Wen-Hua Chen, and Lipika Deka. "Real-time motion planning methods for autonomous on-road driving: State-of-the-art and future research directions." Transportation Research Part C: Emerging Technologies 60 (2015): 416-442.

[6] Pendleton, Scott Drew, Hans Andersen, Xinxin Du, Xiaotong Shen, Malika Meghjani, You Hong Eng, Daniela Rus, and Marcelo H. Ang. "Perception, planning, control, and coordination for autonomous vehicles." Machines 5, no. 1 (2017): 6.

[7] Kaviani, Samira, Marie O'Brien, Jessica Van Brummelen, Homayoun Najjaran, and David Michelson. "INS/GPS localization for reliable cooperative driving." In 2016 IEEE Canadian Conference on Electrical and Computer Engineering (CCECE), pp. 1-4. IEEE, 2016.

[8] Kato, Shin, Sadayuki Tsugawa, Kiyohito Tokuda, Takeshi Matsui, and Haruki Fujii. "Vehicle control algorithms for cooperative driving with automated vehicles and intervehicle communications." IEEE Transactions on intelligent transportation systems 3, no. 3 (2002): 155-161.

[9] Wang, Jiadai, Jiajia Liu, and Nei Kato. "Networking and communications in autonomous driving: A survey." IEEE Communications Surveys & Tutorials 21, no. 2 (2018): 1243-1274.

[10] Fagnant, Daniel J., and Kara Kockelman. "Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations." Transportation Research Part A: Policy and Practice 77 (2015): 167-181.

[11] Boland, Hannah M., Morgan I. Burgett, Aaron J. Etienne, and Robert M. Stwalley III. "An Overview of CAN-BUS Development, Utilization, and Future Potential in Serial Network Messaging for Off-Road Mobile Equipment." Technology in Agriculture (2021).

[12] Bozdal, Mehmet, Mohammad Samie, Sohaib Aslam, and Ian Jennions. "Evaluation of can bus security challenges." Sensors 20, no. 8 (2020): 2364.

[13] Di Natale, Marco, Haibo Zeng, Paolo Giusto, and Arkadeb Ghosal. Understanding and using the controller area network communication protocol: theory and practice. Springer Science & Business Media, 2012.

[14] Hartwich, Florian. "CAN with flexible data-rate." In Proc. iCC, pp. 1-9. Citeseer, 2012.

[15] De Andrade, Ricardo, Kleber N. Hodel, Joao Francisco Justo, Armando M. Laganá, Max Mauro Santos, and Zonghua Gu. "Analytical and experimental performance evaluations of CAN-FD bus." IEEE Access 6 (2018): 21287-21295.

[16] Cheon, Bomu, and Jae Wook Jeon. "The CAN FD network performance analysis using the CANoe." In IEEE ISR 2013, pp. 1-5. IEEE, 2013.

[17] Nguyen, Tien-Hai, Bo Mu Cheon, and Jae Wook Jeon. "CAN FD performance analysis for ECU re-programming using the CANoe." In The 18th IEEE International Symposium on Consumer Electronics (ISCE 2014), pp. 1-4. IEEE, 2014.

[18] Tenruh, Mahmut, Panagiotis Oikonomidis, Periklis Charchalakis, and Elias Stipidis. "Modelling, simulation, and performance analysis of a CAN FD system with SAE benchmark based message set." Proc. 15th Int. CAN Conf. 2015.

[19] Vemparala, Manoj Rohit, Shikhara Yerabati, and Gerardine Immaculate Mary. "Performance analysis of controller area network based safety system in an electric vehicle." 2016 IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT). IEEE, 2016.

[20] Zago, Guilherme Marcon, and Edison Pignaton de Freitas. "A quantitative performance study on CAN and CAN FD vehicular networks." IEEE Transactions on Industrial Electronics 65.5 (2017): 4413-4422.

[21] Kim, Haeri, Wonsuk Yoo, Seoncheol Ha, and Jong-Moon Chung. "In-Vehicle Network Average Response Time Analysis for CAN-FD and Automotive Ethernet." IEEE Transactions on Vehicular Technology (2023).

[22] Rishvanth, D. Valli, and K. Ganesan. "Design of an in-vehicle network (Using LIN, CAN and FlexRay), gateway and its diagnostics using vector CANoe." American Journal of Signal Processing 1.2 (2011): 40-45.

[23] Yong, Shujun, Yunhong Ma, Yifei Zhao, and Lerong Qi. "Analysis of the Influence of CAN Bus Structure on Communication Performance." In IoT as a Service: 5th EAI International Conference, IoTaaS 2019, Xi'an, China, November 16-17, 2019, Proceedings 5, pp. 405-416. Springer International Publishing, 2020.

[24] Hegde, Rajeshwari, Siddarth Kumar, and K. S. Gurumurthy. "The impact of network topologies on the performance of the in-vehicle network." International Journal of Computer Theory and Engineering 5.3 (2013): 405.

[25] Hafeez, Azeem, Hafiz Malik, Omid Avatefipour, Prudhvi Raj Rongali, and Shan Zehra. "Comparative study of can-bus and flexray protocols for in-vehicle communication". No. 2017-01-0017. SAE Technical Paper, 2017.

[26] Ishak, Mohamad Khairi, Omer Ali, Emma Ahmad Sirajuduin, and Lee Shea Qi. "Vehicle Sensors Programming Based On Controller Area Network (CAN) Bus Using Canoe." 2019 16th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON). IEEE, 2019.

[27] Kim, Junkwang, Woo Young Jung, Soon Kwon, and Youngduk Kim. "Performance test of autonomous emergency braking system based on commercial radar." In 2016 5th IIAI International Congress on Advanced Applied Informatics (IIAI-AAI), pp. 1211-1212. IEEE, 2016.

[28] Reddy, AV Durga Ganesh, Gunwant Dhadyalla, and Neelu Kumari. "Experimental validation of CAN to Bluetooth gateway for in-vehicle wireless networks." 2013 International Conference on Emerging Trends in Communication, Control, Signal Processing and Computing Applications (C2SPCA). IEEE, 2013.

[29] Mirza, Naeem, and Ali Nawaz Khan. "Bluetooth low energy based communication framework for intra vehicle wireless sensor networks." 2017 International Conference on Frontiers of Information Technology (FIT). IEEE, 2017.

[30] Almeida, Pedro Miguel Marinho. "Wireless CAN bus bridge." (2019).

[31] Mary, Gerardine Immaculate, and Zachariah C. Alex. "Implementation and Response Time Analysis of Messages in Wireless Controller Area Network." Indian Journal of Science and Technology 8.S8 (2015): 536-541.

[32] Si, Wei, David Starobinski, and Moshe Laifenfeld. "A robust load balancing and routing protocol for intra-car hybrid wired/wireless networks." IEEE Transactions on Mobile Computing 18.2 (2018): 250-263.

[33] Siemuri, Akpojoto, Tobias Glocker, Mike Mekkanen, Kimmo Kauhaniemi, Timo Mantere, and Mohammed Elmusrati. "Design and implementation of a wireless CAN module for marine engines using ZigBee protocol." IET Communications (2023).

[34] Bayilmis, C., Erturk, I., & Ceken, C. (2005, January). Extending CAN segments with IEEE 802.11 WLAN. In The 3rd ACS/IEEE International Conference onComputer Systems and Applications, 2005. (p. 79). IEEE.

[35] Rohit D.Patil, and Prof. V. D. Shinde " Design and Implementation of WIU for CAN/WLAN/CAN Bridge" International Journal Of Innovative Research In Technology,IJIRT , 2015

[36] Purohit, Manish, Piyush Vyas, and Avnish Bora. "Evaluation of MAC protocols using local bridge in high frequency bands based on discrete event simulator tool using analytical approach." In 2017 International Conference on Energy, Communication, Data Analytics and Soft Computing (ICECDS), pp. 2103-2107. IEEE, 2017.

[37] Ozcelik, Ibrahim. "Interconnection of CAN segments through IEEE 802.16 wireless MAN." Journal of Network and Computer Applications 31, no. 4 (2008): 879-890.

[38] Mary, Gerardine Immaculate, Zachariah C. Alex, and Lawrence Jenkins. "Real time analysis of wireless controller area network." ICTACT Journal on Communication Technology 5.3 (2014): 951-8.

[39] Mary, Gerardine Immaculate, and Zachariah C. Alex. "Modelling, analysis and validation of wireless controller area network." International Journal of Engineering Systems Modelling and Simulation 8.1 (2016): 8-19.

[40] Quitin, François, and Michel Osée. "A Wireless Transceiver for Control Area Networks: Proof-of-Concept Implementation." 2023 IEEE 19th International Conference on Factory Communication Systems (WFCS). IEEE, 2023.

[41] Park, Jongjun, Changwon Lee, Jee-Hun Park, Byeong-cheol Choi, and Jeong Gil Ko. "Poster: Exploiting wireless CAN bus bridges for intra-vehicle communications." In 2014 IEEE Vehicular Networking Conference (VNC), pp. 111-112. IEEE, 2014.

[42] Laifenfeld, Moshe, and Tal Philosof. "Wireless controller area network for in-vehicle communication." 2014 IEEE 28th Convention of Electrical & Electronics Engineers in Israel (IEEEI). IEEE, 2014.

[43] Lee, Changwon, Hoon Jeong, Jaehong Ryu, Byeong-Cheol Choi, and JeongGil Ko. "Bringing Down Wires in Vehicles: Interconnecting ECUs using Wireless Connectivity." In Proceedings of the 13th ACM Conference on Embedded Networked Sensor Systems, pp. 465-466. 2015.