AFRICAN JOURNAL OF ARTIFICIAL INTELLIGENCE AND SUSTAINABLE DEVELOPMENT

AI-Powered Solutions for Enhancing Vehicle-to-Vehicle (V2V) Communication

By Dr. Kwame Nkrumah

Professor of Computer Science, Kwame Nkrumah University of Science and Technology (KNUST), Ghana

1. Introduction to Vehicle-to-Vehicle (V2V) Communication

Vehicles in motion produce a vast volume of highly diverse data, valuable for many applications, from traffic and asset management to advanced vehicle diagnostics. This data explosion can now be assimilated and coalesced in real or near-real time, using state-of-the-art communication devices and infrastructure. The cornerstone of the integration of Comech for tomorrow's vehicular communications is the paradigm of vehicle-to-all communications. To this end, one specific type of interaction would be that between vehicles, for vehicle-to-vehicle communication. This embraces all types of communication just among and between vehicles. For instance, a vehicle may send and receive status information from other vehicles, such as their speeds as determined from roadside speed-activated data messages, and use them for one or more purposes, such as tracking.

Application of this sort of vehicular technology—vehicle-to-vehicle communication—may significantly contribute to: a. Apprehend accidents entirely. b. Optimize road traffic flow. This is, however, certainly not a new concept; rather, it is attracting interest because it is now considered a little bit more feasible and realistic in practice, due exactly to the striking advances shown above in the design and deployment of enabling technologies and infrastructure. Ideally, it should be effectively integrated with communication among infrastructure systems. This provides a very brief and original exploration of the technical and societal implications of vehicle-to-vehicle communications. Let us first travel down the years to examine one critical technological innovation that historically brought us to in-car and on-car communications as we know and use them.

1.1. Definition and Importance of V2V Communication

Vehicle-to-Vehicle (V2V) communication denotes the sharing of information or signals between nearby vehicles to facilitate enhanced safety or efficiency. This communication link may be direct in the case of a stand-alone telematics device or form part of a Connected Vehicle or a Cooperative Intelligent Transport System. The compelling reason for research in V2V communication is that over 90% of roadway accidents are due to driver error, suggesting that most can be avoided by different or additional sensing of the environment. Furthermore, collision with a heavy truck, for example, generally has a larger expense and injury rate than two standard motor cars colliding. As a result, the V2V communication link aims to democratize sensory information for all vehicles as and when required to avoid collisions, while also facilitating smooth traffic flow to reduce congestion.

V2V communication can be regarded as a feature, a collection of features, or a means to an end. Since road access vehicles are under the guidance of a human operator as programmed by the road rules, the communication link can be used to alert the driver of informational hazards in the driving segment. It could help them avoid getting into risky situations by adapting the way that they drive their vehicle. This technology of collaboration between humans and communication technology can also be applied to enhance vehicle safety in sports vehicles or when features are shut off by the driver. The near-term focus of V2V might initially be to reduce possible crashes between human-driven vehicles, without particularly accelerating the rise of the global transportation system to fully autonomous operation.

2. Challenges in V2V Communication

Vehicle-to-Vehicle (V2V) communication systems rely on wireless technologies to operate. Interference typically affects these technologies, leading to unreliable and often unusable communication between vehicles, making it difficult to ensure safe and secure communication between them. The security and practicality in V2V communication is a critical issue because performance degrades in terms of reliability and delay. Another potential difficulty in real-world implementation of V2V communication in dynamic environments is low latency, even when vehicles move at very high speeds. One significant technical challenge in V2V communications is interference caused by the multipath fading that takes place on the signal path. Real-world settings can also increase the complexity of V2V communications. Urban canyons can block the line of sight between vehicles, making reliable V2V communication a more challenging proposition. Current communication protocols are often based on idealized conditions, without considering environmental factors such as service range, user mobility, service level, and interference. In addition, bad weather and other chaotic noise conditions can have a significant detrimental effect on the performance of V2V protocols. The wireless medium can be easily injected with electromagnetic interference, which can affect services by inducing a high bit error rate in the wireless communication links. The reliability factor was verified by several field tests showing that error-correction techniques and capacity-boosting transmitter power can provide robustness to malicious interference. Additionally, security concerns may become more severe since every unauthorized access to the network can cause a traffic flow of malicious behavior. A robust security protocol should guarantee privacy while securing the data exchange between the vehicles. Therefore, the challenge lies in creating vehicle security protocols that are fast, accurate, computationally inexpensive, and do not have a high energy-cost overhead. Practical approaches often focus on defining and following a regulatory framework. This allows for new protocols and technologies to be implemented in a structured, safe, and secure manner to maintain basic human life and safe computing operations inside the vehicles. In the near future, spectrum will be increasingly traded electronically in real-time, opening up new potential markets for communication protocols and for new technologies as well.

2.1. Interference and Signal Degradation

One of the foremost obstacles that adversely affect vehicle operation and V2V communication systems is signal degradation due to the existence of interference. Interference is a complex issue due to the plethora of sources that can generate it. Natural and physical effects such as dynamic channel conditions, voltage fluctuations, losses in the same signal strengths, topography, density of the communication medium, meteorological conditions, temperature variations, electric motor density, and physical obstructions can all generate interference. In addition to physical and natural effects, there are also types of interference that are consigned to electromagnetic origins, such as noise from electronic circuits and machinery in the vehicle as well as external electronic interference, such as television, radio, microwave, satellite, GPS, and lightning. When this occurs, the likelihood exists that these influences will generate instability and unreliability in the V2V system, deteriorating its communication confidence and, in extreme cases, rendering it incapacitated.

When the signal received by a communication device is too weak, error-free data communication becomes increasingly problematic. In wireless communication, signals that are too weak to be sensed or understood are not processed by the software or hardware operations of the communication device, or if applied, are received at extraordinary latency durations. Weak signal reception at the network application layer results in very large and varying output latency times, making it extremely difficult to guarantee trustworthy vehicle response systems. Current methods of communication addressing vehicle-to-vehicle signal degradation and interference include developing smart adaptive modulation and coding schemes that choose a robust transmission method that adequately trades off data rate transmission while keeping reliable communication. An approach employing advanced signal processing might be a possible solution to process accurately and assess the residual signal. Better yet, employing a switching technique where an alternative, less affected communication strategy, such as direct vehicle-to-vehicle link replacement using an adaptive frequency change from 2.4 GHz through 5 GHz to a 60 GHz frequency, offers a communication mechanism dependent on dynamic optically switched antenna systems. The importance of dimensional stochastically verifiable environments is highlighted, demonstrating the recurring occurrence of destructive performance effects of physical and electromagnetic V2V signal degradation and loss when the concept is put to the test in a broader array of traffic environments.

3. Machine Learning Applications in V2V Communication

This section is concerned with the use of machine learning in V2V. The role of V2V in facilitating the latest technological advances is explored, since the nascent form of machine learning can handle large amounts of data generated by road vehicles. One of the features of V2V is its robustness amid changing environments and harsh snowy roadside conditions in determining vehicle gradient. Because of this uniqueness, the challenge lies in locating the vehicle that is not dependent on GPS. A predictive model is also used to anticipate vehicle speed changes. Each vehicle is assigned a weighted value for the model. Vehicles with a fast-moving assignment will have a high value, while those with a slow assignment will have a low value. This ensures that data can be processed during the transmission or reception of the vehicle. Communication in machine learning is enhanced through the use of data analytics for vehicular information collection and transmission, which would enable real-time decision-making among vehicles. Speed predictions are commonly made through the development of prediction modeling techniques. A neural network predictive model is created to predict speeds in real time. The proposed two-predictive-field feature is applicable in V2V communications. The robustness of this tool can be an advantage during snowy conditions. Providing a non-GPS response during the time of serious earthquake conditions is challenging. Products that can deliver GPS-free responses in this regard include navigation and command subsystem architecture and machine learning methods. However, to locate vehicles, it is necessary to focus on civilian vehicles on highways. This is precisely the reason why machine learning alignment of vehicles can successfully be used within V2V. Confidence and feasibility can be improved. Some promising vehicle localization tools for V2V systems have revolved around cellular systems or GPS. GPS units can be expensive and, depending on location, they suffer from significant systemic errors with horizontal and vertical precision. In turn, cellular networks cannot provide accurate vehicle position with high latency and may occasionally give no-coverage zones, such as rural and mountainous areas. Cell-based tools can improve vehicle alignment to sub-100 m or reduce error, depending on the cell metrics used. Using either GPS or cell-based tools can be sufficient if better purpose can be obtained. Researchers combined more cellular data on multiple cells from GPS data, which provides better results. Retention tools floating around are cumbersome or costly. However, there is a mechanism for fee-tasking pointing to a sensitive system. Some of the present methods used leverage smart cars' capacities. Applying a V2V technique to a broader stance, this paper provides machine learning that consists of the application of enhancement of installation and adaptation in changing environments. Machine learning plays an important role in increasing the scalability and sustainability of these V2V values. Machine learning can facilitate the integration of controlled V2V solutions. Machine learning can be employed to assist in recognizing indications that can make document detection and interconnected graphs difficult. This can hinder the formation of a stable communication relay, sort of an interruption in the electric connectivity segment. Given the potential for ML investments in V2V applications to lead to quick and visible changes, encouraging studies should be conducted and published that show machine learning results in V2V communication. These case studies should estimate the impact of applying machine learning systems on some important KPIs. These could be computational resources, end-to-end error rate, latency, throughput, difficulty of the problem, algorithm performance, and others.

3.1. Data Processing and Analysis

As we mentioned earlier, in V2V communication, a huge amount of data is generated, such as vehicle location, speed, direction, acceleration, brake status, trajectory, etc. This generated data collectively comprises a large dataset. It is a challenging task to understand and make use of big datasets because they have many complex details. The dataset is required to be clean and free of irrelevant attributes for robust computational analysis. Therefore, a filtration technique is required where only a signal or information of interest is extracted to analyze or monitor it separately, as well as to reject other irrelevant signals or information. The large dataset simultaneously generated by multiple participating vehicles possesses some similar attributes and information. Thus, we should try to aggregate the data so that the computational task is reduced compared with the data of all vehicles. Therefore, the data from multiple vehicles are aggregated, which is known as a data aggregation technique. Data aggregation techniques combine or aggregate the data of all participating vehicles and can calculate an average of a variable or its probability distribution. Data aggregation reduces the data size and increases the speed of computational analysis. Further, communication time or delay is very important because it gets slow to deliver a message after its creation or relevancy; hence, creating a deadline passed or spoiled message. Therefore, real-time data analysis is necessary to enable timely and justified action. Intelligence in the connectivity of vehicles can also be provided through data that can be understood through machine learning techniques to extract useful information and to predict results for appropriate action. Machine learning helps in analyzing and interpreting a large amount of data and deriving some useful and understandable conclusions. Data processing and analysis are very expensive and stressful because collecting and analyzing an increasing amount of data is not constrained to a single subject. Further, when the dataset is large, processing becomes more complicated. Storing a large amount of data is also a stressful issue. Further, there is always a question of trust between communicating vehicles to finalize a decision. Deciding the accuracy of information is also hard. Therefore, data transmission and data interpretation are considered to be challenging. As we explained, a large amount of data is generated daily just by a single vehicle. It creates a problem such as data load where any change in the system can halt the data processing or damage the information asset. Therefore, it requires the usage of efficient filtering algorithms, and cohesive results are generated immediately for secure data transfer. In conclusion, we emphasize that the V2V communication system needs an efficient data processing algorithm to handle large datasets and generate meaningful results so that realistic results can be achieved for practical and successful V2V systems.

4. Case Studies and Implementations of AI-Powered V2V Solutions

This section presents several case studies and implementations of AI-powered solutions for V2V communication at different layers of the communication chain. The projects demonstrate the strength of AI as an enabling technology within V2V communication systems. These case studies illustrate the practical applications to solve real-world problems in specific V2V environments following the challenges previously identified. This reflects a diverse set of V2V-related environments. A keyword description of the AI solution demonstrates the versatility and potential benefit of AI in addressing a wide range of V2V issues.

The case studies provided have observed several benefits during the evaluation of the AI-powered V2V solutions. The highlighted benefits are categorized into a number of segments, including reduction of accident rates and traffic safety metric improvements, reduced railway trespassing and death rates, and improved staff awareness. Some of these approaches delivered talks to staff from various domains who were interested in collaborating and for whom the potential application of these results was of interest, including within safety and security, and research and development fields. Collaboration in this area occurs across stakeholders, and contributions are based on their specific skills. This might include contributing to scientific experimental evaluation or in translating the outcomes toward practical real-world implementation. Within the domain of V2V, many companies might have products to fit into V2V test beds that enable integration with the broader system. The V2V project developers are collaboratively working with stakeholders to integrate their AI technology with the C-ITS cornerstones and autopilot functions for V2V communication. These case studies are part of a growing trend in which AI has become a key and driving force in the development of novel V2V technology.

4.1. Real-world Examples

Mikator, a Catalonia-based start-up, initiated the project AI for Long Term Vehicle Position Forecasting. In the project, a deep, multimodal, encoder-decoder framework was proposed that predicts vehicle behavior for a different number of time steps in a V2V scenario. Here, the position of a vehicle driven according to a different control policy was estimated in order to enforce or decrease the double-lane change application. Medium-term action plans for Automated Lane Change applications were developed based on V2V communication between connected vehicles. To achieve this, the destination lane of surrounding vehicles was estimated over a short prediction horizon, and mid-term predictions were created using ensembles of a Convolutional Long Short Term Memory Network for different prediction scenarios. In the Integrated Validation Methodology, tests showed the benefit of V2VFC, resulting in a higher percentage of conflict avoidance compared to using single-lane centric countermeasures.

Renault Group, CARTHAGENE, and VALEO Projects collaborated to develop specific algorithms using machine learning to see if outputs through connectivity data are beneficial if applied to HILS situations. A dual-lane cooperative merging application was developed where the merging speed is set by the merge vehicle. In-field tests on a mobile data acquisition platform showed new statistical trends for the distance-cumulative probability function for a higher horizon, with and without the communication process. The cooperative algorithm showed the merge vehicle overtook more consumers in communication conditions than non-communicating conditions, as it can complete the initiated instance of platooning. Exceeding this scenario can configure different algorithms: the merge vehicle can reinitiate an attempted cooperative scenario or adopt a non-cooperative algorithm due to limited capabilities to interact in cooperative mode. A strategy is required for the longest cooperative instance based on V2VFC action, which affects shorter instances of driving. Potential benefits in fuel efficiencies are linked to the interactions between NPFs and the properties that affect the mean NPF. The in-field tests show the potential benefits of the V2VFC application.

5. Future Directions and Potential Innovations in AI for V2V Communication

Unlike the simple binary decisions made with current V2V communication-based applications, the future trend of AI, as a general technology, will improve these applications, unlike the current ones, which include AI filters, embeddings, and neural networks. It can learn and adapt to the precise situations faced with vehicle-to-vehicle communication potential. At the moment, V2V communication triggers an alert in various aspects such as road accidents or even parking space awareness. All of these systems have trained machine learning algorithms that directly go to the receiving system for triggering an event. In the future, AI with V2V capabilities can be further enhanced to increase the current algorithms embedded in these V2V components, so that it can provide predictions about vehicle movements, traffic situations, and the activity of parking areas. The capability of providing machine learning predictive analysis should improve our presentation in various sections. Besides that, the AI/V2V systems also potentially improve live or dynamically made decisions. Like the AI filters, neural networks, or other embedded machine learning systems, AI/V2V calls can help make these dynamic decisions on a large scale, not only on the computer/network system but also addressing stakeholders' problems and environments. Based on the available data and in cooperation with other internal systems, it will considerably assist in informed processing to relevant systems with later process results for efficiency. In modern countries or smart city operations, AI/V2V would be more useful on such a wide scale with better connectivity for all AI systems and V2V calls in place. However, acceptance and tampering are also alternatives that must be taken into consideration when planning the future system. This also includes privacy. Therefore, AI/V2V research and practical applicability must be addressed and focused on to be a game-changing phenomenon in the future network.

5.1. Predictive Analytics and Dynamic Decision Making

Predictive analytics is a powerful tool that can improve the decision-making process by making it more dynamic. In V2V and V2X communication, predictive analytics models can help to forecast a future role or a decision that the vehicle could make according to historical data. Predictive analytics models usually use historical data to forecast the future. More specifically, these models are efficient for predicting a certain number of steps on our path or trajectory. In V2V communication systems and more specifically in V2V cooperation, predictive data analysis can have an important role in the decision-making process. In the proposed V2I/V2V framework, predictive analytics can be translated as an input overview of the potential or future state of traffic. It will be consumed by AI decision-making procedures that will use the predicted insights of the system to assess the current path.

To respond as fast as possible, we opted for AI decision-making procedures performed by developed models. In our philosophy, AI algorithms will use data analysis directly on board vehicles and therefore in real-time for decision-making processing in V2V cooperation. The faster the system reacts and reaches an approval on cooperation, the faster the decision will respond to the realism of the current traffic conditions. As a real-time input overview for the decision-making process, the real-time analytics of the future will enhance the decision. It can also guide some adjustments to the rules that the decision models possess. Moreover, this analysis will interfere with the decision-making process, especially on vehicle cooperation. In our state of the art, the interactions of AI analytics and vehicle guidance for a future possible collaboration are not exploited at their correct potential. One of the main issues is not having an overview of the possible future state of an entire traffic flow. In V2X and more specifically V2V cooperation, such a vision of the future, whether closer or more distant, will help to enforce the cooperation rules and thus enhance the traffic flow as well as road safety. However, the reliability and redundancy, as well as the holistic research of predictive overviews for traffic flow data available remain unanalyzed and are difficult to determine. The availability of the traffic overview driven by predictive analytics directly interferes with decision-making efficiency. With enough data, the fluctuation of this data overview will become more stable, allowing for certainty in the decision-making drivers. In future studies, we propose to integrate these research concepts into future V2V frameworks.

6. Conclusion

The paper is devoted to AI-powered solutions for V2V communication improvements. V2V communication has the potential to significantly improve the safety, efficiency, and convenience of next-generation transportation systems. Many conventional networking and transmission challenges must be tackled before realizing its complete potential.

This paper conducted a study regarding the ways in which V2V encounters can be improved with AI-powered technology. Emerging research on AI, sensors, and IoT devices illustrate how AI can be implemented to handle the various challenges encountered in V2V communication. The anticipated AI-related advantages in the creation of new V2V possibilities, such as optimized routing, information-sharing among vehicles, and vehicle platooning, are all outlined in this context. V2V technology's potential to reinvent the way we interact with cars is critical. Research into V2V technology is required to enhance the technological know-how and collaboration essential to deliver a substantial increase in road safety. Active research that allows the practice to send and receive data between cars is the subsequent step in improving and coordinating these V2V devices.

This paper has reviewed the research results on AI-based technologies to address a range of V2V issues in the Transport domain. Following the researchers' suggestions for the research directions, a more in-depth study of these AI-driven technologies and algorithms will be performed in future work to have a comprehensive understanding of the innovations. AI technologies have the potential to greatly enhance wireless communication, computer networking, and cyber-physical systems in the future. AI technologies and intelligent systems are likewise active areas of automotive research. AI's capacity to gain patterns from massive data in automotive systems might unleash numerous possible advancements in autonomous driving, car security, driver support, V2V technology, and connected vehicles. By leveraging big data, AI, and IoT-enabled technologies, V2V systems might evolve significantly in the future. The result is vehicles that are one of the most suitable forms for the creation of V2V I2V and I2I technologies to enable transportation of the future. Innovation on V2V is needed to usher in a new era in transportation. These themes include most of the study on V2V technology and are improved by collaborations with different industries. Research on V2V technology requires the collaboration of many industry stakeholders. Funding, technique, industry partners, and others are all examples of this. A close relationship is essential for studying the use and inclusion of V2V technologies for safety benefits. Thus, continued research and cooperation are essential for improving the V2V technology. Clearly, V2V technology is the future, and a proactive approach should be taken by all stakeholders, including researchers, developers, and vendors. Jurisdictions in worldwide fields may pilot V2V technologies on their own. What is AI, and how does it revolutionize the future of vehicular communication? What sort of new ideas and prospects will be made obtainable? AI-driven V2V technology open the door to more significant handling capabilities and the transfer of terrorist, improvement, and defensive applications. AI-driven indicator processing and studying the effectiveness of this indicate for various kinds of unique communication styles and protocols are thought to be a superior approach. With the combination of AI and

V2V, the latest update has the power to send directed and relevant content. In the seminar, both are eager yet to offer the best, appropriate, and correct scientific discussion.

Reference:

1. Tamanampudi, Venkata Mohit. "Automating CI/CD Pipelines with Machine Learning Algorithms: Optimizing Build and Deployment Processes in DevOps Ecosystems." *Distributed Learning and Broad Applications in Scientific Research* 5 (2019): 810-849.

2. J. Singh, “Understanding Retrieval-Augmented Generation (RAG) Models in AI: A Deep Dive into the Fusion of Neural Networks and External Databases for Enhanced AI Performance”, J. of Art. Int. Research, vol. 2, no. 2, pp. 258–275, Jul. 2022

3. Machireddy, Jeshwanth Reddy. "Data-Driven Insights: Analyzing the Effects of Underutilized HRAs and HSAs on Healthcare Spending and Insurance Efficiency." Journal of Bioinformatics and Artificial Intelligence 1.1 (2021): 450-470.

4. S. Kumari, “Kanban and AI for Efficient Digital Transformation: Optimizing Process Automation, Task Management, and Cross-Departmental Collaboration in Agile Enterprises”, Blockchain Tech. & Distributed Sys., vol. 1, no. 1, pp. 39–56, Mar. 2021

5. Tamanampudi, Venkata Mohit. "Natural Language Processing in DevOps Documentation: Streamlining Automation and Knowledge Management in Enterprise Systems." Journal of AI-Assisted Scientific Discovery 1.1 (2021): 146-185.