Revolutionizing Autonomous Mobility: Harnessing VANET and LoRaWAN for Infrastructure-Free V2V Communication for Self-Driving Vehicles

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Abstract— **In the realm of autonomous mobility, the advancement of Vehicle-to-Vehicle (V2V) communication technology stands as a critical enabler for safer and more efficient transportation systems. This article explores the integration of Vehicular Ad-Hoc Networks (VANETs) and LoRaWAN for infrastructure-free V2V communication, highlighting their transformative potential in shaping the future of self-driving vehicles. By harnessing the capabilities of VANETs and LoRaWAN, autonomous vehicles can communicate seamlessly without reliance on centralized infrastructure, paving the way for enhanced situational awareness, cooperative maneuvering, and collision avoidance. Through an in-depth analysis of these technologies, this article elucidates their benefits, challenges, and implications for revolutionizing autonomous mobility.**

Keywords: V2V communication, V2I communication, Infrastructure free V2V communication, VANET, LoRaWAN, Safety, Autonomous vehicles.

I. INTRODUCTION

In the rapidly evolving landscape of autonomous mobility, the integration of robust Vehicle-to- Vehicle (V2V) communication systems stands as a cornerstone for ensuring safer and more efficient transportation networks. V2V communication enables vehicles to exchange vital information in real-time, facilitating cooperative maneuvers, collision avoidance, and enhanced traffic flow management. As the demand for seamless communication between autonomous vehicles grows, innovative solutions such as Vehicular Ad-Hoc Networks (VANETs) and LoRaWAN are emerging as frontrunners in enabling infrastructure-free V2V communication [1][2]. VANETs have long been hailed as a key enabler of V2V communication [3][10], leveraging vehicle mounted sensors and dedicated roadside units to create ad-hoc networks. These networks enable vehicles to exchange critical data such as speed, position, Localization, Priority Rights, Acceleration/Deceleration, Direction, Traffic Conditions, Vehicle Identification (IDs) and Communication Range, enhancing over all road safety and efficiency. However, VANETs face limitations such as limited coverage range, scalability challenges, and susceptibility to network congestion, particularly in densely populated urban environments. Enter LoRaWAN[3][13], a wireless communication technology renowned for its long-range capabili- ties and low power consumption. LoRaWAN offers an enticing solution for infrastructure-free V2V communication, allowing vehicles to communicate directly without the need for centralized infrastruc-ture. By leveraging LoRaWAN's robust communi- cation protocols and adaptive data rate capabilities, vehicles can establish reliable and efficient V2V networks even in remote or challenging terrain. The integration of VANET[1] and LoRaWAN[2] presents a promising approach to overcome the limitations of standalone V2V communication technologies. By combining the localized communication capabilities of VANETs with the long- range connectivity of LoRaWAN, autonomous vehicles can benefit from seamless communication across varied environments. This hybrid approach enables vehicles to communicate directly in urban areas where VANETs excel, while leveraging LoRaWAN's extended range in rural or remote settings [4]. Furthermore, infrastructure-free V2V communication[10] offers several transformative benefits for autonomous mobility:

- **Real-Time Situational Awareness:** By exchanging real-time data with nearby vehicles, autonomous vehicles gain a comprehensive understanding of their surrounding environment, including the presence of other vehicles, pedestrians, and potential hazards.
- **Cooperative Maneuvering:** Infrastructure-free V2V communication facilitates cooperative maneuvers among autonomous vehicles, allowing them to coordinate actions such as merging, lane changing, and intersection crossing more efficiently and safely.
- **Collision Avoidance:** Autonomous vehicles can leverage V2V communication to detect and avoid potential collisions proactively. By sharing their trajectories and intentions, vehicles can collaboratively adjust their paths to prevent accidents and ensure smooth traffic flow.

While LoRaWAN provides a feasible infrastructure-free solution for V2V communication, especially in areas where traditional infrastructure is lacking, it has significant limitations compared to VANETs. Combining both technologies, leveraging the strengths of each, could provide a more robust solution for diverse V2V communication needs.

II. V2V SCOPE AND VISION

A. V2V communication

Vehicle-to-Vehicle (V2V) communication is a technology enabling cars and other vehicles to exchange information wirelessly, including speed, position,localization and direction, fostering real-time decision-making and cooperative maneuvers. This technology aims to enhance road safety, improve traffic management, and support autonomous driving by enabling direct communication between vehicles. Key aspects of V2V communication include safety features, where vehicles share critical information like speed, location, and braking status, aiding in accident prevention by alerting drivers to potential hazards[1]. Moreover, V2V communication aids in traffic management by sharing data on traffic conditions, allowing drivers to adjust routes and reduce congestion. For autonomous vehicles, V2Vcommunication is essential for coordinating maneuvers such as lane changes and platooning, leading to smoother driving patterns. Data exchange typically occurs over a Dedicated Short-Range Communications (DSRC) frequency or Cellular V2X (C-V2X), ensuring fast and reliable communication[5]. Standards are being developed to ensure interoperability between vehicles from different manufacturers, over seen by organizations like the Institute of Electrical and Electronics Engineers (IEEE) and the Society of Automotive Engineers (SAE). Additionally, V2V systems are designed with security measures to protect against hacking, and privacy concerns are addressed by anonymizing data to safeguard individual vehicle information[6].

B. Understanding VANETs

Vehicular Ad-Hoc Networks (VANETs) are self-configuring networks formed by vehicles equipped with communication capabilities. In VANETs, vehicles communicate with each other and with road side infrastructure[1], exchanging information about traffic conditions, road hazards, and other relevant data. VANET communication relies on dedicated wireless communication protocols, such as IEEE802.11p, to enable real-time data exchange between vehicles. By leveraging VANET communication, vehicles enhance situational awareness, improve traffic flow, and enable cooperative driving applications[7].

C. Vehicular Networks Architecture

The current VANET architecture consists of several main components, including the base station, Road Side Unit (RSU), and vehicles, as shown in Figure 1. These components can communicate with each other via V2V and V2I communications. Additionally, through infrastructure-to-infrastructure (I2I) communications, messages can be exchanged between RSUs and between the RSU and the base station[8].

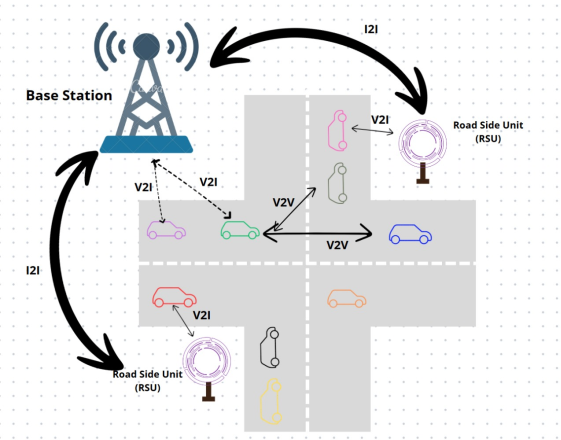


FIG 1: VANET architecture.

In Figure 1, a simple road intersection includes several vehicles, two RSUs, and a base station interconnected by fast wired connections. Vehicles can exchange information through V2V communication directly with nearby vehicles. If a vehicle is out of range, multi-hop communication is required, which can lead to high latency, particularly in safety-critical applications. Alternatively, vehicles can use cellular transmission to send data to the base station, which then relays it to the recipient, potentially overloading the terrestrial network. Lastly, vehicles can transmit to the nearest RSU, which identifies and routes data with minimal latency using fast wired connections. RSUs play a crucial role in future VANET architectures, with various deployment strategies proposed for maximizing their effectiveness. The figure distinguishes between V2V and V2I communications [9].

D. Limitations of VANETs in V2V Communication

Vehicle-to-Vehicle (V2V) communication using Vehicular Ad Hoc Networks (VANETs) is a promising technology for enhancing road safety, traffic efficiency, and enabling various intelligent transportation applications. However, there are several limitations of V2V communication in the absence of infrastructure. In summary, while V2V communication using VANETs offers significant potential, its effectiveness is limited in the absence of supporting infrastructure due to challenges in connectivity, scalability, reliability, security, coordination, and adoption. Overcoming these limitations requires advancements in technology, widespread adoption, and possibly hybrid approaches that combine V2V communication with infrastructure-based support [10].

III. THE POWER OF INFRASTRUCTURE-FREE V2V COMMUNICAT

The importance of infrastructure-free V2V communication is paramount in addressing the challenges faced by developing countries in implementing V2V systems. Infrastructure-free V2V communication eliminates the reliance on centralized infrastructure such as RSUs [12], making it a more accessible and cost-effective solution, particularly in regions with limited resources. By enabling vehicles to communicate directly without external dependencies, infrastructure-free V2V communication enhances road safety and facilitates efficient traffic flow even in areas lacking well- established infrastructure. Therefore, integrating infrastructure-free V2V communication alongside traditional V2V systems becomes crucial for ensuring comprehensive safety and connectivity on the roads, especially in developing countries striving to enhance their transportation networks and reduce traffic-related accidents and fatalities[10][11].

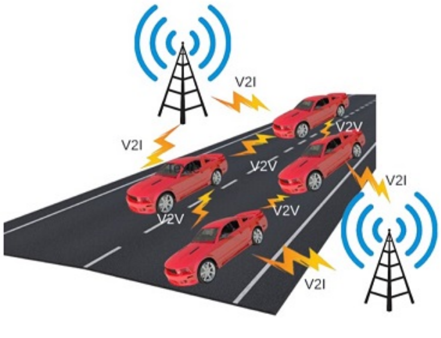


FIG 2: V2V V2I communication.

- **Benefits:** Enhanced reliability, extended communication range, and interoperability with existing infrastructure.
- **Challenges:** Dependence on roadside infrastructure, limited scalability, and potential privacy concerns due to centralized control.

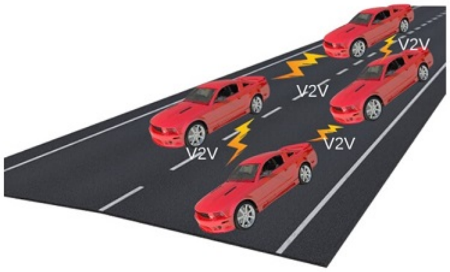


FIG 3: Infrastructure-free V2V communication.

- **Benefits:** Decentralization, scalability, resilience, and enhanced privacy.

A. *Exploring Infrastructure-Free V2V Communication Using LoRaWAN*

Exploring infrastructure-Free V2V communication using LoRaWAN Vehicle-to-Vehicle (V2V) communication is pivotal in shaping the future of autonomous and connected vehicles, promising enhanced safety and more efficient traffic management. While traditional V2V systems often rely on extensive infrastructure like cellular networks or Dedicated Short-Range Communications (DSRC), alternative solutions that reduce infrastructure dependencies are gaining interest. One such solution is using Long Range Wide Area Network (LoRaWAN) technology for V2V communication. This article delves into how LoRaWAN can be employed for infrastructure-freeV2Vcommunication, highlighting its potential benefits and inherent challenges.

B. *How LoRaWAN Fits into V2V Communication*

LoRaWAN occupies a unique position in V2V (Vehicle-to-Vehicle) communication, offering long-range capabilities, low power usage, and excellent penetration abilities. Designed for distances ranging from 2 to 5 kilometers in urban settings and up to 15 kilometers in rural areas, LoRaWAN efficiently transmits basic vehicle telemetry, ensuring operational continuity even if primary power systems fail, thanks to its low power consumption.

Implementing LoRaWAN in V2V communication supports an infrastructure-free approach, crucial in environments lacking reliable traditional infrastructure like cellular networks or roadside units. Each vehicle acts as a node within the LoRaWAN network, capable of relaying messages to nearby vehicles or a central server, even in remote areas, facilitating direct communication between vehicles.

The data exchanged between vehicles includes speed, direction, position, localization, and sensor data crucial for collision avoidance, route optimization, and cooperative driving. Despite its low data rate limitations, LoRaWAN transmits small packets of essential data sufficient for critical V2V interactions.

LoRaWAN offers substantial benefits in V2V communications, providing infrastructure independence crucial in impractical traditional network settings. Its cost-effectiveness compared to cellular networks or complex wireless systems reduces financial strain on governments and communities. Additionally, LoRaWAN networks scale impressively, allowing expansion by simply adding more vehicle nodes, without increasing costs or complexity significantly.

IV. OUR APPROCH

Utilizing LoRaWANt echnology to enable seamless communication between vehicles at intersections, thereby eliminating the need for traditional infrastructure such as traffic lights or roadside units. Here's how our approach works: Implementing V2V communication using LoRaWAN at crossroads involves a systematic approach to enable vehicles to exchange critical information without relying on traditional traffic infrastructure such as traffic lights or roadside units. Each vehicle is equipped with LoRaWAN modules, initialized with specific parameters like frequency and data rate. As vehicles approach the intersection, they continuously broadcast and listen for messages containing essential data such as vehicle ID, position, speed, direction, priority rights and intended maneuvers. This real-time data exchange allows vehicles to autonomously determine priority based on arrival time and road rules. For instance, a vehicle approaching a stop sign will broadcast a stop message, prompting other vehicles to yield. By coordinating these signals, vehicles can collaboratively manage intersection navigation, significantly enhancing safety and efficiency. Error handling mechanisms ensure robustness, addressing potential communication failures or data loss. This innovative use of LoRaWAN fosters an infrastructure-free environment, streamlining traffic flow and supporting the seamless operation of autonomous vehicles.

A. V2V implementation using LoRaWAN

To implement V2V communication using LoRaWAN in a crossroad without traffic lights while respecting the rules of the road, including priority and stop panel signs, you'll need to consider the following steps and logic:

- **Initialization:**

Initialize LoRaWAN modules on each vehicle with appropriate parameters like frequency, data rate, and transmit power.

- **Message Format:**

Define a message format for V2V communication including fields for vehicle ID, position, speed, direction, and intention (e.g., turn left, turn right, go straight).

- **Detection:**

Vehicles continuously listen for messages from nearby vehicles. If a vehicle detects another within range, it starts communication.

- **Exchange of Information:**

Vehicles exchange information regarding their position, speed, and intention using LoRaWAN packets.

- **Decision Making:**

Based on received information, each vehicle decides its priority at the intersection. If a vehicle has a priority (e.g., it reached the intersection first), it sends a priority message.

- **Stop Sign Detection:**

Vehicles detect stop panel signs at the intersection. If a vehicle reaches a stop sign, it sends a stop message to other vehicles.

- **Priority Evaluation:**

Vehicles evaluate the received messages to determine if any vehicle has priority or if any vehicle needs to stop based on the received stop messages.

- **Execution of Priority:**

If a vehicle has priority, it proceeds through the intersection according to the road rules. If a vehicle receives a stop message, it stops at the intersection.

- **Communication of Intentions:**

Each vehicle communicates its intention to other vehicles, indicating whether it will turn left, turn right, or go straight. **Coordination:** Vehicles coordinate their movements to avoid collisions and ensure safe passage through the intersection.

- **Repetition:**

The process of detection, information exchange, decision-making, and coordination repeats as vehicles approach and navigate the intersection.

- **Error Handling:**

Implement error handling mechanisms to address communication failures, packet loss, or other issues that may arise during V2V communication.

B. Priority Management

At a suburban intersection devoid of traditional traffic lights, four vehicles, each equipped with LoRaWAN-enabled V2V communication systems, approach simultaneously. Vehicle B, positioned to the right of Vehicle A and possessing the subsequent right of way, proceeds first, followed by Vehicle C, which yields to Vehicle B in accordance with traffic regulations. Vehicle D patiently awaits its turn, yielding to Vehicles A and B due to their lower IDs. Finally, Vehicle A, the leader of the group, passes through the intersection last, completing the orderly passage of all four vehicles. Through the seamless coordination facilitated by V2V communication, these vehicles navigate the intersection safely and efficiently, prioritizing passage based on their positions and IDs without the need for traffic lights.

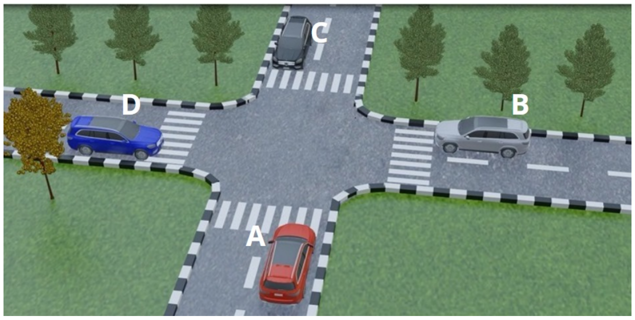


FIG 4: V2V Communication at Crossroads.

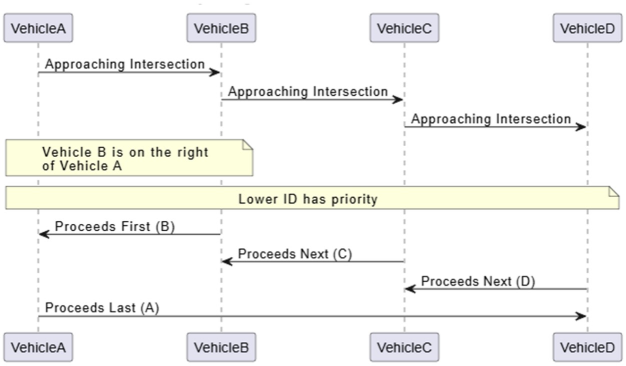


FIG 5: Sequence Diagram"Intersection Priority Management via V2V Communication with LoRaWAN".

C. Stop Sign Panels

At a suburban crossroad where conventional traffic lights are absent, four vehicles equipped with LoRaWAN-enabled V2V communication systems approach simultaneously. As they converge, each vehicle detects the presence of stop sign panels, prompting Vehicles A and C to come to a halt. Meanwhile, Vehicle B, positioned to the right of Vehicle A, proceeds first, in accordance with traffic regulations and its subsequent right of way. Vehicle C yields to Vehicle B, following the established traffic hierarchy. Meanwhile, Vehicle D patiently waits its turn, yielding to Vehicles A and B due to their lower IDs. Once Vehicles A, B, and C have navigated the intersection, Vehicle A, as the leader, passes through last, completing the orderly passage of all four vehicles. Through seamless coordination facilitated by V2V communication, the vehicles prioritize passage based on their positions and IDs, ensuring safe and efficient navigation of the intersection without the need for traditional traffic lights.

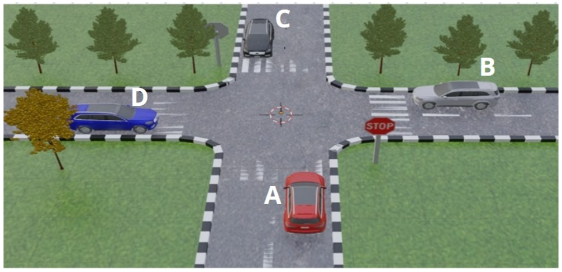


FIG 5: V2V Communication and Stop Sign Panels.

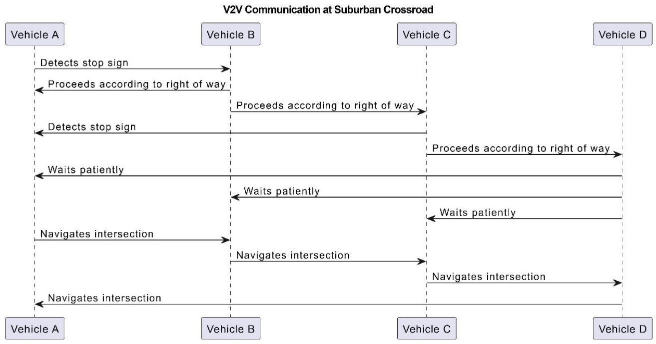


FIG 6: Sequence Diagram"Intersection Management with V2V Communication and Stop Sign Panels with LoRaWAN".

D. Presence of an external vehicle

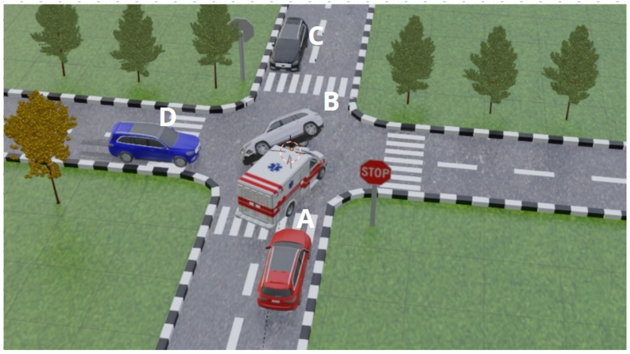


FIG 7: The Crucial Role of V2V Communication in Emergency Response.

In a suburban crossroad devoid of conventional traffic lights, four vehicles equipped with V2V communication systems converge simultaneously, alongside the presence of an ambulance requiring priority passage. As the vehicles approach, Vehicle A and Vehicle C encounter stop sign panels, obliging them to come to a halt. Meanwhile, Vehicle B, positioned to the right of Vehicle A, holds subsequent right of way, and Vehicle D respects priority rights. Sensing the urgency of the situation, the ambulance communicates its priority status to the other vehicles via V2V communication, necessitating immediate passage. Acknowledging this, Vehicles A and C yield to the ambulance and await their turn at the intersection. Vehicle B proceeds smoothly through the intersection, adhering to traffic regulations, while Vehicle D yields to both Vehicle B and the ambulance. With the path cleared, the ambulance takes precedence and navigates the intersection swiftly. Once the ambulance has passed, Vehicles A and C receive confirmation through V2V communication to proceed, ensuring the orderly movement of traffic while prioritizing safety and emergency response. This scenario underscores the critical role of V2V communication in facilitating efficient and safe intersection management, even in the absence of traditional traffic control mechanisms.

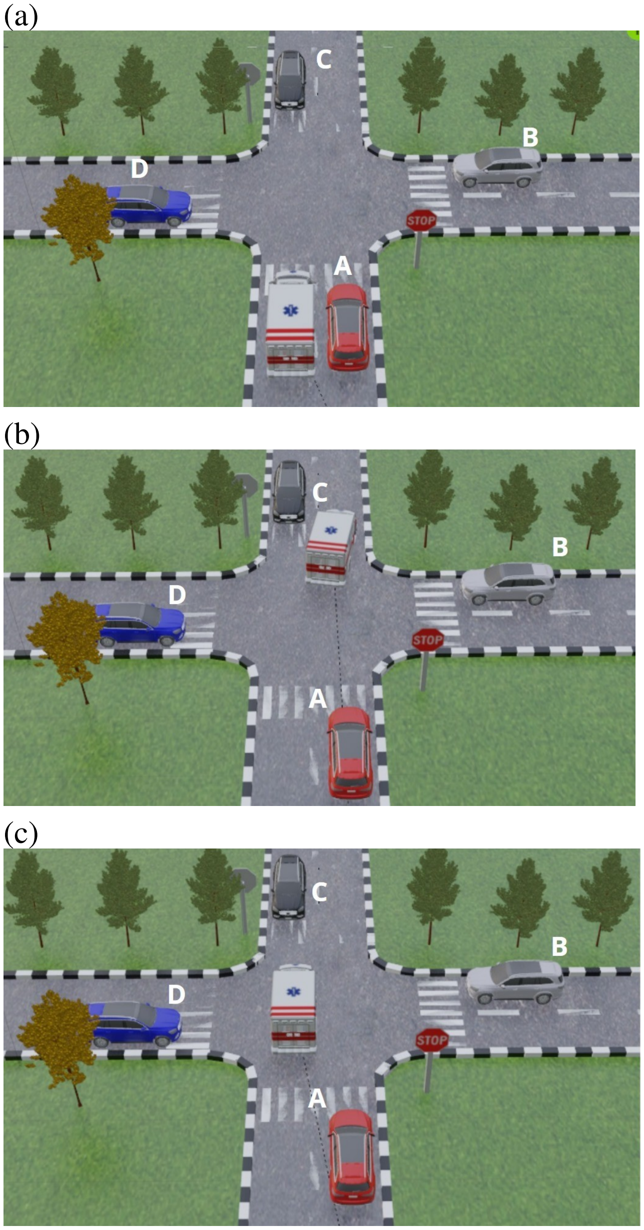

(a)
(b)
(c)

FIG 8: (a)(b)(c) V2V Communication:”presence of an ambulance with priority to pass first”

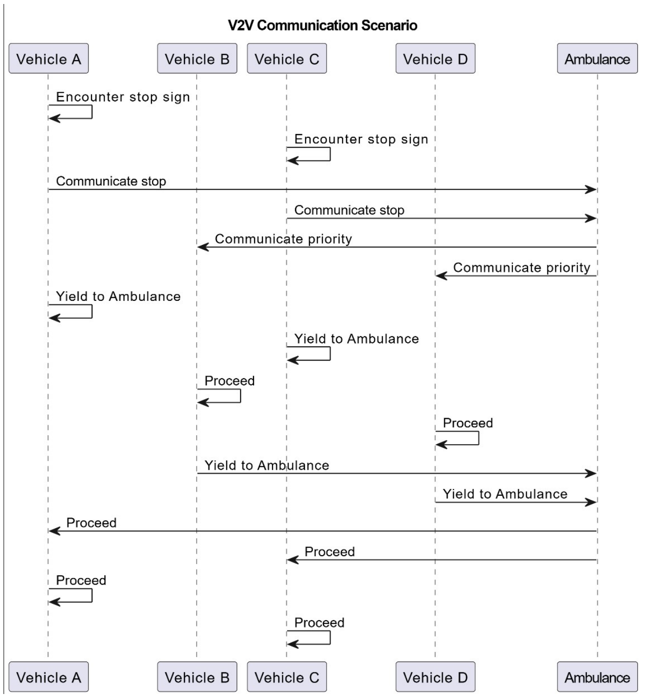


FIG 9: Sequence Diagram”Intersection Management with V2V Communication and presence of ambulance with LoRaWAN”.

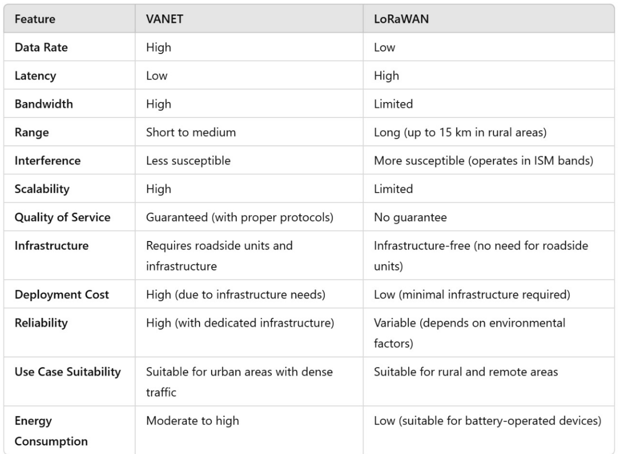
V. LEVERAGING VANET AND LORAWAN FOR SEAMLESS CONNECTIVITY

A. Limitations of LoRaWAN for Infrastructure-Free V2V Communication

- **Low Data Rate:** LoRaWAN is designed for low data rate applications. This means it may not be suitable for applications that require high-speed data transfer, which is often necessary for real-time V2V communication.
- **Latency:** The inherent latency in LoRaWAN communication can be a critical limitation for V2V communication where real-time data exchange is crucial.
- **Limited Bandwidth:** The bandwidth offered by LoRaWAN is limited, which can restrict the amount of data that can be transferred at any given time.
- **Interference:** Operating in the unlicensed ISM bands, LoRaWAN can be susceptible to interference from other devices using the same frequency spectrum.
- **Scalability:** While LoRaWAN can cover long distances, the number of devices that can be

supported in a given area is limited due to the network's capacity constraints.

- **Quality of Service (QoS):** LoRaWAN does not guarantee QoS, which can be a problem for critical V2V communication where the timing and reliability of data transmission are essential.
- **Range Variability:** The effective range of LoRaWAN can vary significantly based on environmental factors, which can affect the reliability of communication in dynamic vehicular environments.



Feature	VANET	LoRaWAN
Data Rate	High	Low
Latency	Low	High
Bandwidth	High	Limited
Range	Short to medium	Long (up to 15 km in rural areas)
Interference	Less susceptible	More susceptible (operates in ISM bands)
Scalability	High	Limited
Quality of Service	Guaranteed (with proper protocols)	No guarantee
Infrastructure	Requires roadside units and infrastructure	Infrastructure-free (no need for roadside units)
Deployment Cost	High (due to infrastructure needs)	Low (minimal infrastructure required)
Reliability	High (with dedicated infrastructure)	Variable (depends on environmental factors)
Use Case Suitability	Suitable for urban areas with dense traffic	Suitable for rural and remote areas
Energy Consumption	Moderate to high	Low (suitable for battery-operated devices)

Table 1: VANET vs. LoRaWAN for V2V Communication

while LoRaWAN provides a feasible infrastructure-free solution for V2V communication, especially in areas where traditional infrastructure is lacking, it has significant limitations compared to VANETs. Combining both technologies, leveraging the strengths of each, could provide a more robust solution for diverse V2V communication needs.

B. Combining VANET and LoRaWAN for V2V Communication

Combining VANET and LoRaWAN for V2V communication leverages the high-speed, low-latency benefits of VANET when infrastructure is present and the long-range, low-power advantages of LoRaWAN in infrastructure-free environments, ensuring reliable communication across diverse scenarios, enhancing the safety and efficiency of autonomous vehicle operations.

Vehicles are equipped with dual-mode communication units that support both VANET (Wi-Fi, DSRC) and LoRaWAN modules, switching between technologies based on infrastructure availability. They monitor for roadside units (RSUs) or other VANET infrastructure, prioritizing VANET when detected and switching to LoRaWAN otherwise. This approach utilizes a common message format for V2V communication, including vehicle ID, position, speed, Localization, Priority Rights, Acceleration/Deceleration,direction and intention, facilitating effective data exchange in active communication modes.

VI. CONCLUSION

The integration of LoRaWAN and VANET technologies offers a promising solution for seamless Vehicle-to-Vehicle (V2V) communication in autonomous vehicles. LoRaWAN is ideal for infrastructure-free environments due to its long-range, low-power capabilities, while VANETs provide high-bandwidth communication suited for infrastructure-rich settings. A hybrid system combining both can switch dynamically based on infrastructure availability. However, securing this hybrid system is challenging, necessitating future research to enhance security for data integrity and privacy, ensuring safe and efficient autonomous mobility.

REFERENCES

[1] Aghabagherloo, A., Delavar, M., Mohajeri, J., Salmasizadeh, M., Preneel, B. An efficient and physically secure privacy-preserving authentication scheme for Vehicular Ad-hoc NETworks (VANETs). IEEE Access, 10, 93831-93844. 2022.

[2] Leonardi, L., Bello, L. L., Patti, G. MRT-LoRa: A multi-hop real-time communication protocol for industrial IoT applications over LoRa networks. Computer Communications, 199, 72-86. February 2023.

[3] Heinzelman, W. R., Chandrakasan, A., Balakrishnan, H. Energy-efficient communication protocol for wireless microsensor networks. In Proceedings of the 33rd IEEE annual Hawaii international conference on system sciences, Hawaii, USA, 4-7 January 2000.

[4] Nurwarsito, H., Umam, M. Y. Performance Analysis of Temporally Ordered Routing Algorithm Protocol and Zone Routing Protocol on Vehicular Ad-Hoc Network in Urban Environment. In 3rd IEEE International Seminar on Research of Information Technology and Intelligent Systems (ISRITI) (pp. 176-181). Yogyakarta, Indonesia 10-11 December, 2020.

[5] Yu Liu, Francois Dion and Subir K Biswas. Dedicated Short-Range Wireless Communications for Intelligent Transportation System Applications: State of the Art. Journal of the Transportation Research, January 2005.

[6] Miguel Baguena; Sergio Mar´ınez Tornell; Alvaro Torres; Carlos Tavares Calafate. ”VACaMobil: VANET car mobility manager for OMNeT++”. The IEEE International Conference on Communications Workshops (ICC), Budapest, Hungary, 09-13 June 2013

[7] Ketut Bayu Yogha. ”A Study of V2V Communication on VANET: Characteristic, Challenges and Research Trends”. JISA (Journal Informatika dan Sains), Vol. 04, No. 01, June 2021.

[8] Thenuka Karunathilake and Anna Förster. “A Survey on Mobile Road Side Units in VANETs”. MDPI, Journal Vehicles 2022.

[9] Ronald Adrian; Selo Sulistyo; I Wayan Mustika. ”A Study on Communication System in VANET”. The 4th International Conference on Science and Technology (ICST), Yogyakarta, Indonesia, August 2018.

[10] Bilal E. Bilgin, V.C. Gungor. Performance Comparison of IEEE 802.11p and IEEE 802.11b for Vehicle-to-Vehicle Communications in Highway, Rural, and Urban Areas, International Journal of Vehicular Technology, January 2013

[11] Dhaya Kanthavel, S.K.B. Sangeetha, K.P. Keerthana. “An empirical study of vehicle to infrastructure communications - An intense learning of smart infrastructure for safety and mobility”, The International Journal of Intelligent Networks, Vol. 2, Pages 77-82, 2021.

[12] OUCHENE Faiza; Boukhatem Lila; GUEROUI Mourad. ”The Involvement of RSUs in VANETs: Survey and Perspectives”, The International Journal of Computational Engineering Research (IJCER), Vol. 3, Issue. 7, July 2013.

[13] [13] Khandaker Foysal Haque; Ahmed Abdelgawad; Venkata Pras- anth Yanambaka and Kumar Yelamarthi. ”LoRa Architecture for V2X Communication : An Experimental Evaluation with Vehicles on the Move”. MDPI, Journal Sensors, December 2020.