An Investigation into the LoRaWAN Solution in Facilitating Communication for Traveler Informative Services

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Abstract

The present era has evolved from conventional vehicles to intelligent vehicles that are endowed with advanced communication systems that provide the driver with assistance or notifications. Intelligent Transportation System (ITS) that has advanced connectivity capabilities that can connect Vehicle-to-everything (V2X) and enhance communication between automobiles and infrastructure. This research evaluates LoRa as a viable technology for meeting the communication needs of VANETs. Long Range (LoRa) technology uses the Long Range Wide Area Network (LoRaWAN) protocol to communicate. It has surged in widespread acceptance due to the low cost of its LoRa devices and LoRa-based gateways. This technology enhances safety and communication capabilities by enabling interaction with adjacent vehicles and infrastructures. This article proposes a VANET communication prototype that utilizes LoRaWAN technology. We created a proof-of-concept implementation and demonstrated its performance in laboratory tests the proposed prototype for transmitting traveler Information from LoRa-enabled modules is sent to a cloud server using a gateway. The evaluation verifies the efficacy of the secure communication pathway. Experimental results with a LoRa-enabled prototype device demonstrate a 99.5% success rate for vehicular communication.

Keywords: Intelligent Transportation System, Long Range, Long Range Wide Area Network, Vehicular Ad-Hoc Networks, Vehicle-to-Everything Communication.

1 Introduction

The rapid progress in wireless technology, along with the rise of the Internet of Things (IoT), has introduced a new way of communication that is both affordable and widespread. This advancement shows potential for alleviating the difficulties linked to the implementation of Intelligent Transportation System (ITS) [1]-[2] applications. By integrating with IoT, ITS can utilize advanced technologies in processing, storing, and communicating data. This enables the development of the Internet of Vehicles (IoV). Vehicular ad-hoc networks (VANETs) and Roadside Units (RSU) provide efficient communication between vehicles and infrastructure to gather traffic data and enhance traffic conditions. VANETs communication can be classified as: Vehicle-to-Vehicle (V2V) communication, which involves communication between vehicles, Vehicle-to-Infrastructure (V2I) communication, which involves communication between vehicles and infrastructure; and Vehicle-to-Everything (V2X) communications, which involve information transmission between vehicles, the Internet gateways, and transport infrastructure.VANETs consist of vehicles equipped with onboard units (OBUs), antennas, and several other sensors. An OBU is a computational unit installed in a vehicle with many communication interface modules.

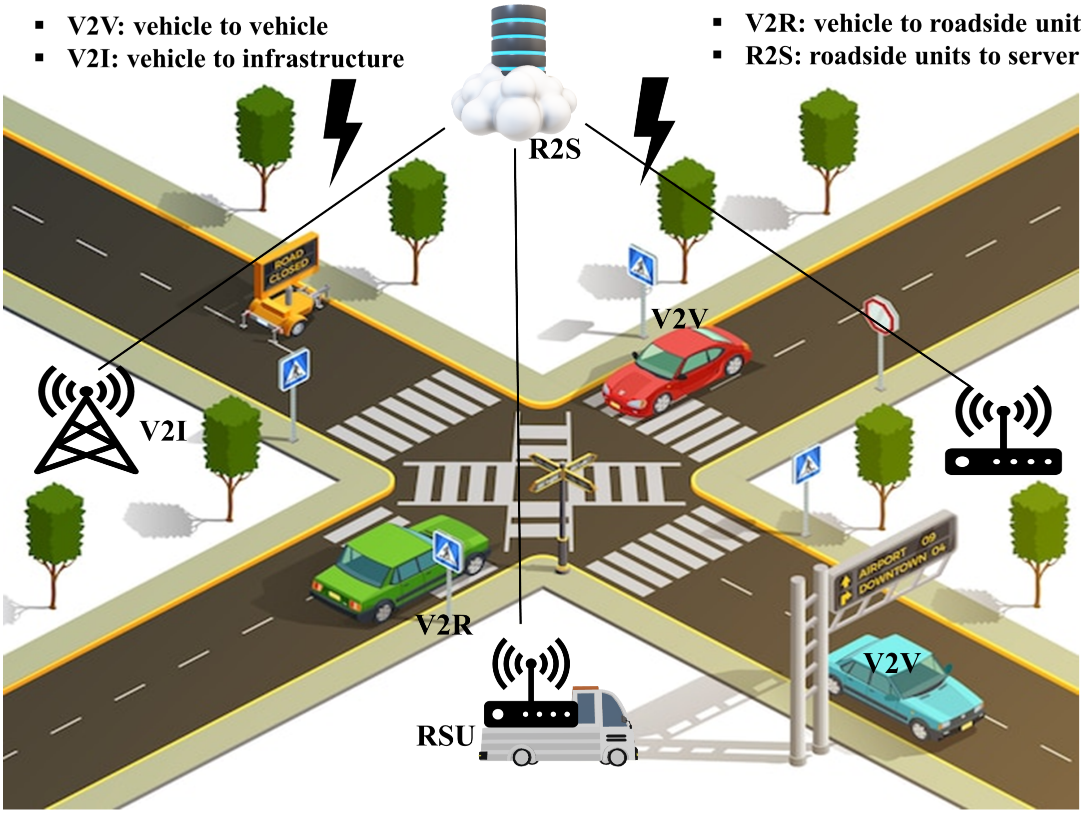

Figure 1: Vehicular Communication Technology Enhances Traveler Information.

Dedicated Short-Range Communication (DSRC) and cellular networks are popular VANET technologies. In the foreseeable future, a single technology is unlikely to provide a wide range of V2X applications for many vehicles. DSRC is popular for its low latency and adaptability to vehicle situations, although scalability issues arise from its infrastructure's high investment requirements for wider adoption. Satellite communication is inefficient for VANETs due to reliability, cost, and power consumption [3].
These problems greatly increase the intricacy of developing efficient communication networks. To overcome these challenges, we offer a thorough examination of LoRa IoT technology as a means of communication support for VANETs, along with the incorporation of routing protocols to achieve the predetermined goals of operating below 1 GHz and having excellent signal propagation and penetration across barriers.
A solution to address the communication needs of ITS is proposed as a prototype model in this work. Fig.1 highlights the components of an ITS. Vehicle Connectivity (VC): The vehicles are outfitted with communication modules to facilitate real-time data sharing. Communication Infrastructure (CI): Establishing a strong communication infrastructure to support V2X communication. Use an effective communication network and protocols to ensure seamless connectivity. Centralized Data Evaluation: Centralized servers evaluate data linked to vehicles.VANETs can regularly communicate traffic data using different communication technologies [4].

1.1 Motivation

In the field of ITS, the key to successful communication is carefully choosing the best vehicle sequences to allow information to flow smoothly, despite the unpredictable and ever-changing nature of the vehicular environment. Current cellular networks are already overloaded due to increased mobile data traffic, so off-the-shelf cellular infrastructures may not be capable of supporting a large number of connected vehicles. LoRaWAN, as

Table 1: Comparing LoRaWAN and IEEE802.11p to cellular technology [5].

Performance Metrics	**LoRaWAN**	**IEEE802.11p**	**Cellular**
Power Consumption	Low	High	Moderate
Integration with IoT Devices	Extensive	Limited	Limited
Flexibility	Wide development	Limited development	Limited development
Scalability	High	Moderate	High
Penetration	Penetrate obstacles	Limited by obstacles	High
Range	More than 15 kilometres	10 to 100 meters	Varies based on technology
Maximum no. of Nodes	2000	Up to 1 million	Varies based on network capacity
Robustness	High	Medium	High

highlighted in Table1, is a powerful and influential force in the rapidly changing transportation industry, where being connected is no longer just a luxury but an essential requirement. As we enter the era of Vehicle-to-Everything (V2X) communication, the use of LoRaWAN technology represents a significant shift in how vehicles can be connect and their surroundings [6].

The LoRa Alliance [7] is in charge of LoRaWAN, a transmission protocol that is effective for VANET communication. LoRaWAN is a minimal power consumption application with a large-area network of things that can connect to regional, national, and even global networks. Low power consumption and long-distance transmission are two advantages of adopting LoRa technology in VANETs. According to research investigations, the following are the identified limitations in creating dependable vehicular communication: The aforementioned limitations can be effectively mitigated with the implementation of LoRa technology.

-For real-time VANET applications, LoRaWAN can be optimized to provide low-latency and consistent data transmissions for vehicular communication.

-LoRaWAN technology overcomes vehicle interference, especially in highly populated cities, ensuring reliable communication.

-LoRaWAN implementation protects VANET mobile and stationary infrastructure against hostile assaults, preserving communication integrity and confidentiality.

-LoRaWAN's adaptability ensures continuous and reliable communication in VANETs, even when dynamic network topology disrupts data flow.

LoRaWAN can meet the diverse communication requirements of VANETS communication technology, making it a central focus in ITS development.

1.2 Contribution

The main contributions of this investigation are outlined as follows:

- Investigation of a solution to evolve vehicular communication utilizing existing infrastructure to accommodate extremely dynamic vehicles and researching the scalability and long-range communication capabilities of LoRaWAN while exploring routing strategies to enhance communication channels.

- Development and execution of a prototype solution. The scenario focuses on V2V communication. The goal is to provide a comprehensive solution for connected vehicles, which includes tracking the vehicle, monitoring its operational parameters, and providing real-time emergency notifications.

- Conducting thorough prototype testing to replicate real-life situations. The prototype demonstrated strong performance throughout testing trials, confirming its effectiveness in improving driving safety and aiding emergency management.

1.3 Outline

The paper is organized in the following manner: Section 2 provides a comprehensive review of relevant research findings and specifically focuses on the features and applications of LoRa technology. Furthermore, it highlights the advantages of implementing LoRaWAN as a communication technology that offers long-range and low-power capabilities for VANETs. Section 3 will discuss the network and architectural model of our suggested solution. Section 4 focuses on the hardware testbed comprising information flow and optimization of the LoRaWAN protocol. Section 5 presents the performance evaluation of the proposed LoRaWAN-based ITS solution, which is supported by trials. Additionally, it includes a discussion of the outcomes obtained. Section 6 concludes the work and is followed by a discussion on prospects.

2 LoRa and LoRaWAN Architecture

Several technologies are available that enable wireless connectivity for IoT devices. LoRa has significantly succeeded in the low-power wide-area network (LPWAN) field . It has been widely used in many environments to efficiently transmit small data packets over great distances. This radio technology is specifically designed to function inside the subgigahertz band of the electromagnetic spectrum. It utilizes chirp spread spectrum (CSS) modulation, which is capable of withstanding multipath fading and is well-suited for situations with high levels of noise. The system driven by LoRa offers a data transfer rate of many kilobits per second, extending over a distance of more than 10 km in outdoor, rural environments while consuming minimal power [8].

In recent years, LoRaWAN has gained prominence as an IoT technology that has captured the attention of academics in the field of Vehicular VANETs, leading to the development of several investigations.

LoRaWAN utilizes a two-tiered design, which is further explained in the description of the experimental testbed. The first type involves wireless links between end-node devices and the surrounding gateways using a single-hop topology (i.e., star topology) [9]. Each gateway functions like a simplified base station in mobile communications, transmitting messages to and from the wired backend. To minimize infrastructure costs, the gateways treat communications as opaque and simply tunnel them into the backhaul. The backend refers to the second tier of a system, which is comprised of multiple logical servers that are often connected over an IP-based network. Put simply, the backend might exist either locally (inside an Intranet) or in the cloud (on the Internet). The RSUs are linked to a Network Server (NS) that oversees the network's operations. The NS is connected to at least one Application Server (AS), which allows integration with end-user applications, usually using a message-oriented middleware like a MQTT Broker. In the majority of VANET scenarios, communication operates on an event-driven paradigm. This means that a device sends an uplink message and then receives two downlink messages one after the other, rather than at the same time. Currently, the available options for reception on Windows are RX1 and RX2. The RX1 communication characteristics are determined based on the specifications. These parameters are obtained from the same uplink transmission and use the same channel. However, there may be a tiny difference in the Spreading Factor (SF). However, RX2 utilizes pre-established channel and spreading factor settings, namely the default requirements in the European Union, which are set at 869.525 MHz with SF12 @ Bandwidth (BW) = 125 kHz. This makes sure that it stays at a right angle to RX1, which improves the reliability of communication in the LoRaWAN architecture made just for VANETs [10].

2.1 Research Gaps

The majority of existing research primarily focuses on the implementation of wireless infrastructure that is effective in supporting nodes with low-cost and low-power consumption. Conversely, less emphasis has been placed on the promptness of data exchanges and the dependability of communication. It has been discovered that the research solution presented so far does not adequately guarantee the confirmation of dependable message transmission. Furthermore, these methods lack certainty in driving to the desired location and fail to adequately handle challenges in urban areas, as they have not been evaluated in such situations. Therefore, to meet the requirements of ITS applications that require fast transmission and minimal packet loss to maintain the efficient functionality of VANETs, we suggest using a LoRaWAN routing protocol. This protocol establishes fast routes while preventing latency, providing message delivery confirmation and seamless transmission, and possibly using RSUs for reliability. Our proposed communication technology solution for meeting ITS requirements. In the following sections, we explain our network model and how it could revolutionize ITS and improve road safety.

3 Proposed Communication System Architecture

The objective is to enhance the efficiency of communication as a traveler informative where LPWAN is utilized as the IoT infrastructure [11]. A conceptual framework for demonstrating VANETs for ITS includes architecture, communication protocols, and integration with LoRaWAN technology. The following section provides detailed information on each of these components.

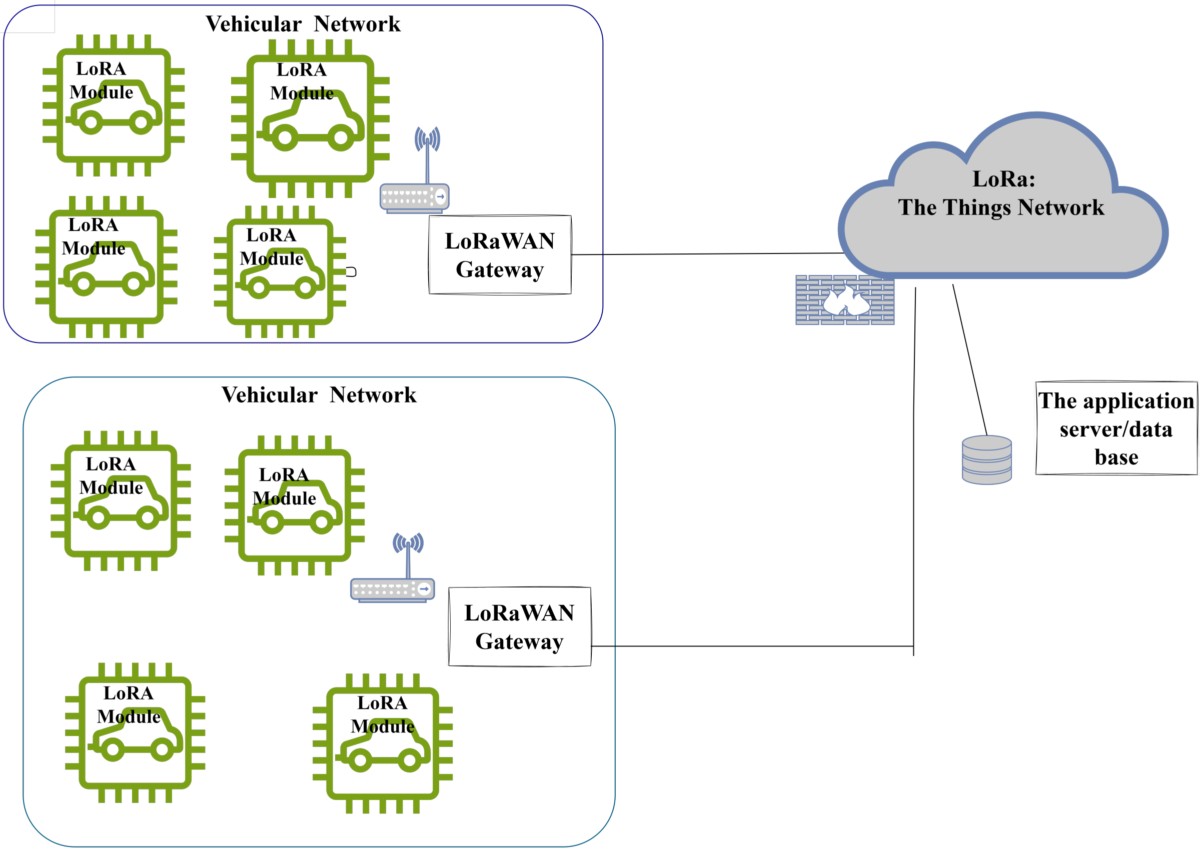

Figure 2: Architecture: Network Model using LoRa communication technology.

The illustrated architecture Fig.2 enables communication for the ITS through the use of OBUs that are equipped with LoRa modules and installed into vehicles. These OBUs provide V2V communication and connect with RSUs to establish V2I communication. The RSUs, which are connected to TTN on the backend, interact with the application server. This server has the responsibility of handling emergency data and distributing it to suitable for traveler information.
Every node in the LoRa network is assigned a device-specific identification, which is crucial for the RSU to determine the sender of transmitted data or messages. This distinct identity functions as a digital mark for each node, guaranteeing that every piece of information transmitted via the network can be linked to its exact origin. By utilizing this identification technique, the RSU is able to precisely determine the source node that is responsible for creating the data. This enables effective communication and focused reactions to emergent events. This functionality improves the overall dependability, safety, and ability to track communication inside the LoRa network, which are crucial aspects in the context of ITS and emergency management systems [12].

3.1 Routing Protocol

A routing protocol is utilized to enable the best route from the source to the destination vehicular node, which is a crucial component of establishing communication in VANETs. To achieve this, we conducted a comparative review of existing routing protocols specifically optimized for our considered scenario to achieve real-time and efficient routing [13]. Out of all the existing routing protocols in the literature [14], the Ad-Hoc On-Demand

Distance Vector (AODV) protocol was selected as the most preferred. AODV functions by commencing a route discovery procedure through the sending of Route Request (RREQ) packets from the source node to the destination node. Once a Route Reply (RREP) is received, the found route is used for future data delivery. The communication system's effectiveness was optimized by enhancing the packet structure in a targeted manner, specifically designed for LoRa communication. This enhancement focuses on critical performance metrics, leading to enhanced data transmission efficiency . This optimization guarantees that our communication system not only exploits the advantages of AODV but also takes full advantage of the distinctive capabilities of LoRa technology, hence improving overall performance and reliability. Route maintenance is a crucial element of VANETs to ensure uninterrupted and dependable communication between vehicles. Once a route is created, it is crucial to regularly evaluate its validity to avoid any disruptions. This is accomplished by periodically exchanging Hello Packets among the nodes that are involved. These packets function as a method of verifying the existence and condition of nearby nodes, enabling each node to certify the ongoing accessibility of its established routes, as illustrated in Figure 3.

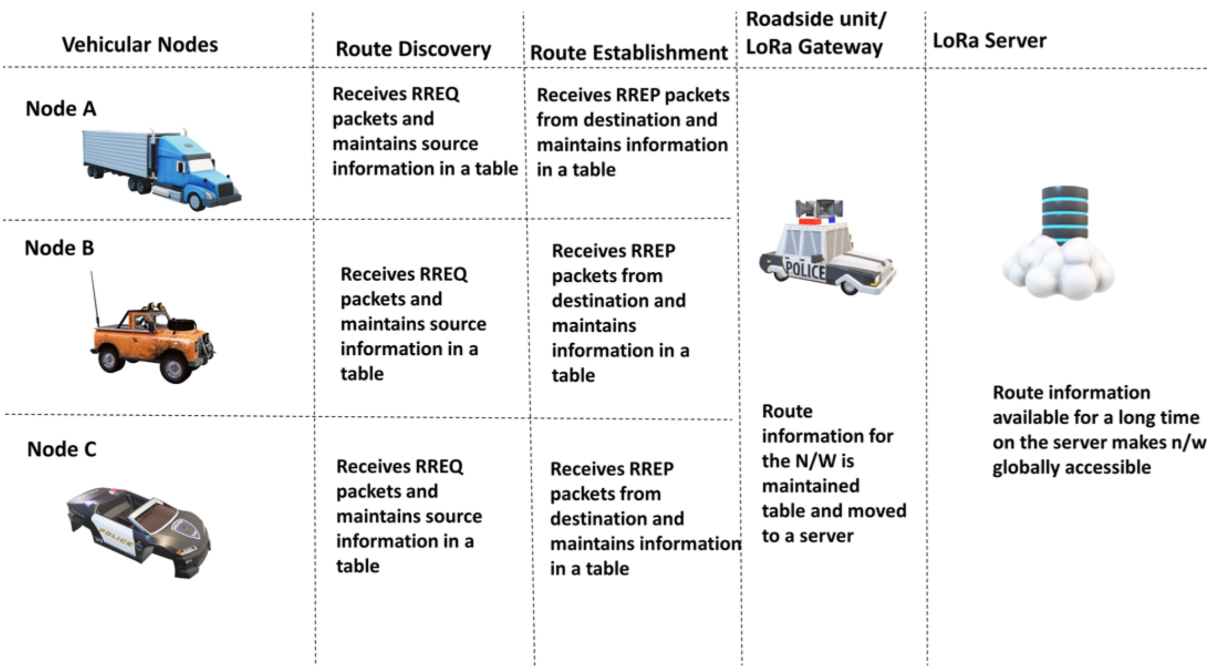

Figure 3: AODV routing protocol integrated with LoRa

In addition, a proactive strategy is performed to improve the reliability of communication by addressing probable errors in message delivery. If a payload packet fails to reach its intended destination, a duplicate of the message is instantly sent to a designated RSU. This duplication guarantees that important communications are not lost during transportation, even in the event of unexpected network interruptions or node malfunctions. Furthermore, the system makes use of the ever-changing nature of vehicular mobility. Once the destination node enters the network's coverage range, the message that was not delivered before is smoothly transmitted to it. This dynamic routing strategy reduces the requirement for expensive re-transmissions and guarantees efficient message delivery, hence enhancing the overall dependability and efficacy of the VANET communication system.

4 Experimental Testbed

The test bed comprises dependable power supplies, high-gain antennas, LoRaWAN gateways, and network servers. Data collection primarily includes gathering communication metrics and analytics, all of which are safeguarded by end-to-end encryption to ensure security provided by LoRaWAN protocol. Testing involves assessing dependability, latency, coverage, and scalability in real-world settings by considering different ambient conditions and vehicle speeds.

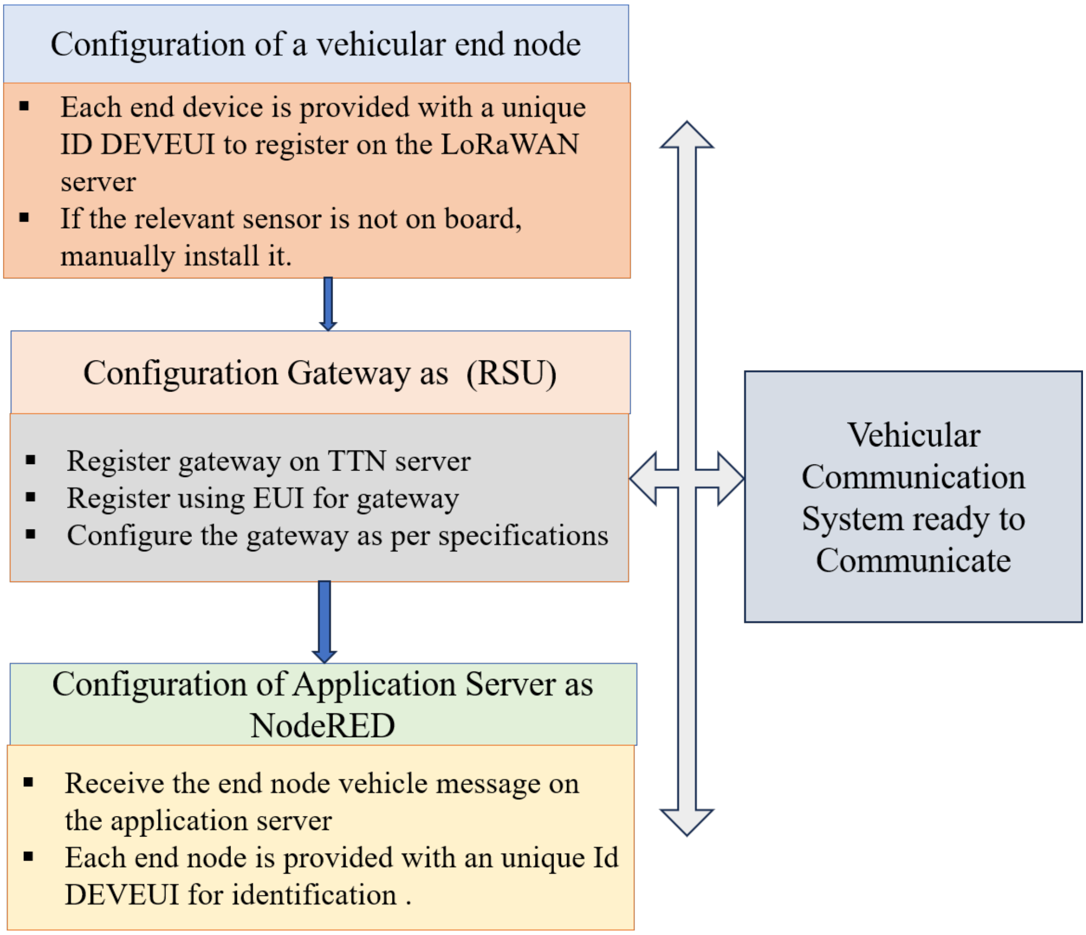

Figure 4: Flowchart of Vehicle Communication

Figure 4 illustrates the flowchart for vehicular communication, which includes the setting of each LoRa module and the connection of each node to the LoRaWAN server and the application server. This section provides an in-depth discussion of the hardware and software development process, specifically focusing on the different solutions experimented with. These solutions include the hardware and transceiver platform, the network setup, and the settings used for data transmission.

4.1 Hardware Setup

Each vehicle in the deployment of ITS is equipped with an RAK3172 module [15]. This module is built with an STM32WLE5CC system-on-chip, which provides strong control and management functionalities.

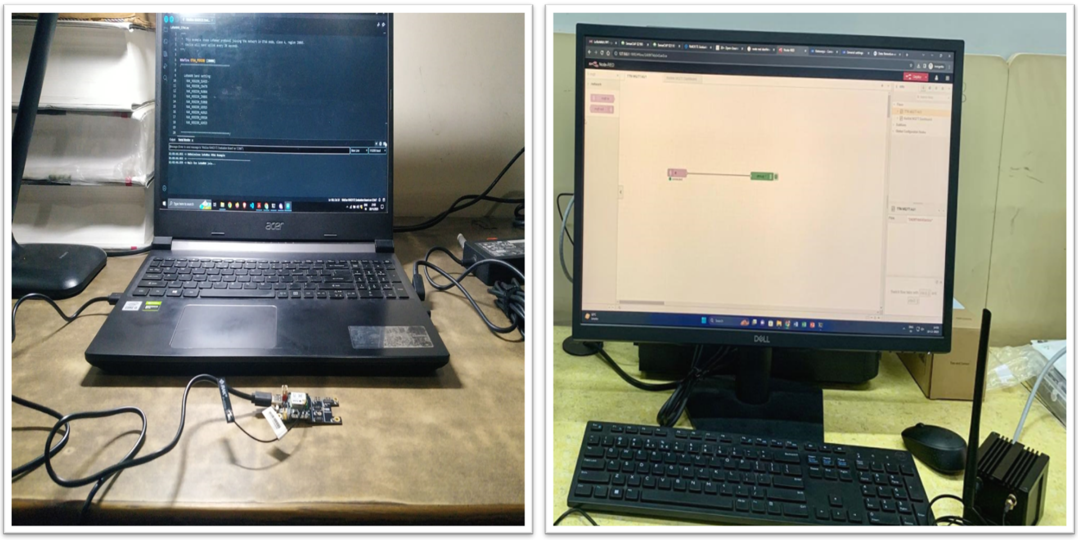

Figure 5: OBU as LoRa Module for Vehicular communication tested in laboratory

Fig.5 depicts the OBU LoRa modules that enable dependable communication in vehicles. These modules use LoRaWAN for long-range, low-power connectivity. This arrangement improves vehicle network safety and responsiveness in critical situations. The RAK3172 module conforms to the rigorous requirements of the LoRaWAN 1.0.3 Class A, B, and C specifications, guaranteeing compatibility and interoperability with different LoRaWAN networks. The chosen operational frequency band for our ITS implementation is the India IN865 band. The selection of this particular frequency band is based on its appropriateness for applications within the regulatory framework of India, offering an ideal combination of coverage, range, and adherence to regulations. A Raspberry Pi Compute Module 4 (CM4), a Power Supply (PS) module, and a LoRa concentrator IP core are all components that are incorporated into the LoRaWAN Gateway RAK7394 WisGate Developer CM4 [16]. The CM4 is responsible for providing solid processing capabilities, while the PS module guarantees dependable power management performance. Considering that the LoRa concentrator IP core makes it possible to handle LoRaWAN communication effectively, this gateway is an excellent choice for the development and deployment of LoRaWAN applications for our scenario.

4.2 Experimental Reference Model for Travel Informative Services

This subsection provides an overview of the reference architecture used to experimentally evaluate the proposed LoRaWAN communication model. The objective is to enhance the efficiency of communication by utilizing low-power, long-range, wide-area networks as the backbone for IoT. As per the LoRaWAN requirements, the join operation requires each vehicle node to have its own distinct AppKey root key and DevEUI identifier. Each vehicle on the backend side must be configured individually. A flow is conducted once at the beginning to handle the join procedure and collect the "nwkSKey" and "appSkey" session keys from the backend for authentication and encryption. This is done using the Over The Air Activation (OTAA) method, which is typically utilized in real deployments. The uplink and downlink flow in vehicular nodes both incorporate a timestamping function, which enables the tracking of each vehicle at the time of generating the uplink message

and receiving the associated downlink acknowledgment. These vehicle nodes collect the local epoch time of the CPU, facilitating accurate timing analysis. During all the trials conducted, which occurred in identical locations with consistent levels of interference, one particular vehicular node established a wireless connection with another vehicular node. Additionally, it was also connected to a LoRaWAN infrastructure that incorporated a network server and an application backend server.
The complete backward compatibility of the suggested method has been demonstrated by evaluating two distinct scenarios. In the first scenario, one vehicular node is connected to another vehicular node. The backend infrastructure belongs to the cloud-hosted TTN network, which is discussed in this article. In the second scenario, a vehicle is linked to the LoRaWAN gateway, which is supported by the TTN network and an open-source NodeRED solution for the application server.

5 Results and Analysis

The connection is typically event-based, with the device sending an uplink, followed by two exclusive downlinks receiving windows as RX1 and RX2. The specifications dictate that the communication parameters in RX1 are obtained from the same uplink, using the same channel, although the spreading factor (SF) may have a slight difference. RX2 uses the set channel and spreading factor values because the default settings in the European Union are 869 MHz for Data Rate (DR)0-SF12 with a bandwidth of 125 kHz. This makes sure that it always lines up with RX1[17].
The system employs the LoRaWAN protocol to transmit data packets to the LoRaWAN server using the LoRaWAN gateway, which acts as a roadside unit (RSU). The RSU establishes a connection with The Things Network (TTN), which is a cloud server for LoRaWAN, using the internet. The location of the vehicular node can be identified by examining the LoRa packets it transmits, as LoRaWAN gateways are equipped with a Global Positioning System (GPS). The GPS data obtained from the LoRaWAN server is transmitted to the LoRaWAN geolocation services, which subsequently furnish the vehicle's precise location.

5.1 Experiment With Vehicle-to-Vehicle Communication

The scenario involves direct wireless connections between vehicular nodes and nearby Gateways (GWs). Each GW functions as a simplified base station in mobile communications, transmitting messages to and from the backend.
The Node-RED dashboard visually represents the information exchange among vehicles, presenting the position, speed, direction, and inter-vehicle distance for each vehicle. The data is gathered and sent over LoRa packets to the LoRaWAN gateway, which functions as a RSU. The RSU transmits this information to the TTN server. The TTN server analyzes the data and continuously updates the Node-RED dashboard, offering a detailed view of vehicle dynamics and distances between vehicles. This improves situational awareness and cooperation among connected vehicles, as illustrated in Fig6.

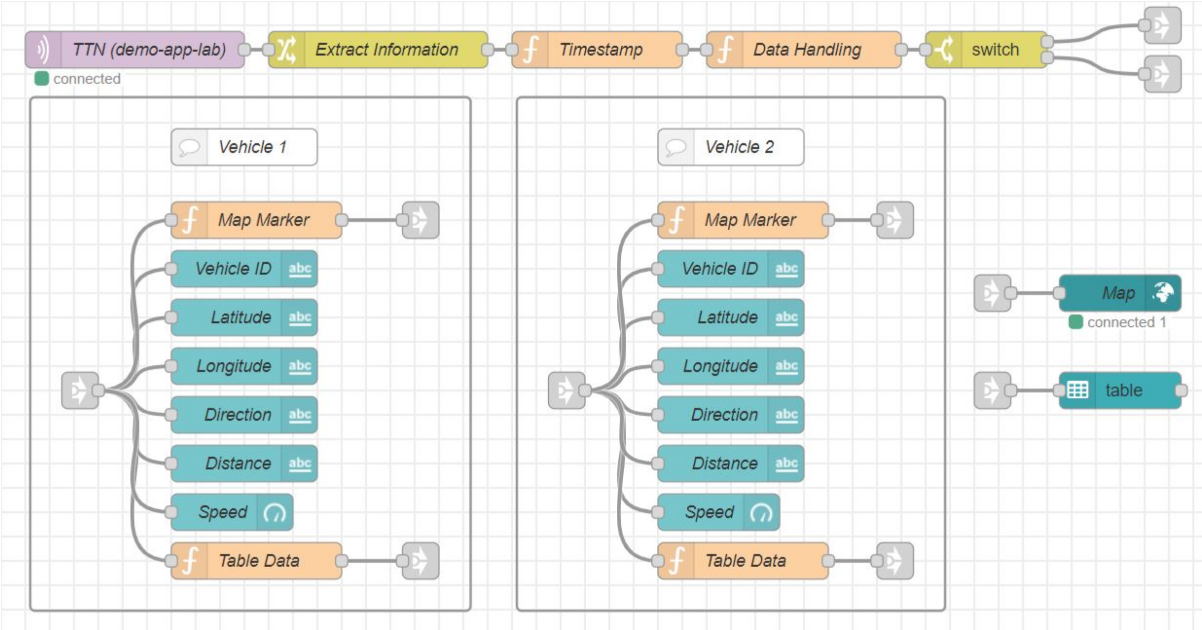

Figure 6: The vehicular node design includes Node-RED flows for the uplink (top) and downlink (bottom) of the virtual device (verified LoRaWAN messages).

5.2 Performance metrics for the prototype ensure Quality of Service (QoS)

i) **Received Signal Strength Indicator (RSSI):** of LoRaWAN communication in vehicles: The signal quality received by vehicular nodes is evaluated using a key parameter. It measures the vehicular node's ability to receive signals from the RSUs. In the context of LoRaWAN, a higher signal strength guarantees more dependable communication, which is essential for swiftly and precisely sending emergency notifications. Vehicles equipped with LoRaWAN can constantly check the RSSI to evaluate the strength and reliability of their connection to the RSU. This strategy guarantees the resilience and reliability of the LoRaWAN communication network, especially in situations when vehicles are traveling at high velocities or are situated in areas with possible signal obstacles. As a result, the prompt delivery of messages is upheld, leading to improved road safety and effective traffic control. Fig7 shows good RSSI levels are essential for efficient communication as vehicles enter the gateway's communication range. With an RSSI of -29 dBm, the signal strength is robust, enabling seamless and dependable data transfer. When the RSSI drops below -34 dBm, the signal strength diminishes, potentially compromising the clarity and dependability of the communication if not effectively handled.

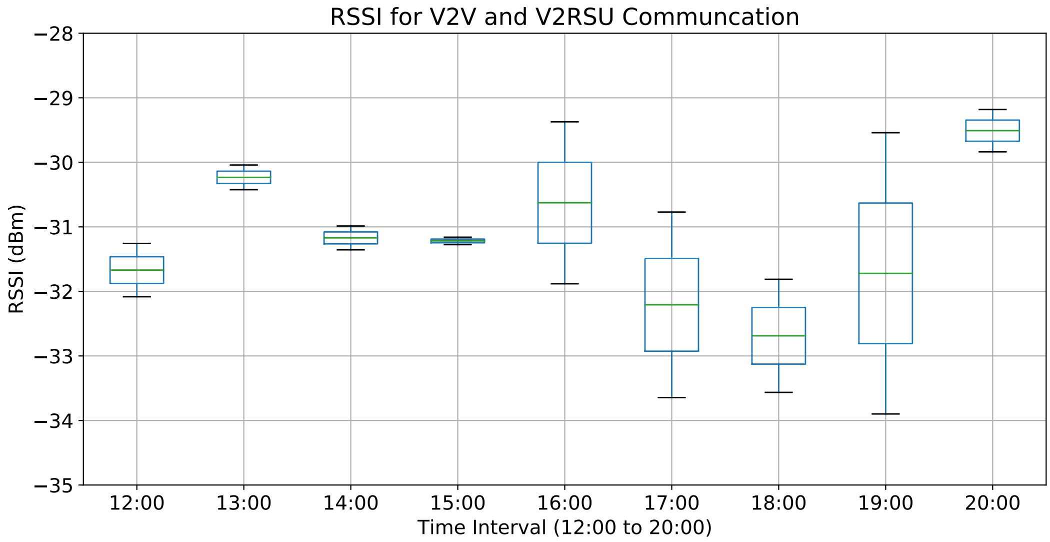

Figure 7: RSSI for V2V-V2RSU communication over time.

ii) **The Signal-to-Noise Ratio (SNR):** is an essential performance measure used to evaluate the quality of received signals in LoRaWAN communication systems. SNR is a measure of the proportion of signal power to noise power. It indicates the ability to identify the original signal from background noise and interference. An elevated SNR is crucial to guaranteeing the precise interpretation of the sent data by the receiver. As the vehicle moves farther away from the gateway, the RSSI and SNR numbers decline considerably. The decrease in SNR has a negative effect on the clarity of the signal and the reliability of communication.

Therefore, it is crucial to maintain appropriate SNR levels to ensure effective communication in vehicles and the timely delivery of emergency alert messages, as depicted in the graph of SNR for our prototype in Fig.8. An SNR between 12 and 14 guarantees a clear and recognizable signal from noise, which is crucial for the precision of emergency alarm messages. The acquired RSSI and SNR values greatly enhance the viability of our suggested proof-of-concept for utilizing LoRaWAN to enable connectivity for travel information services. High RSSI values imply strong signal strength. This is critical for sustaining a constant connection in various travel settings. Similarly, when the SNR is favorable, the signal is of good quality and has little interference.

This improves the reliability and clarity of the communicated information. The combination of these favorable indicators clearly shows that LoRaWAN is capable of efficiently facilitating the smooth transmission of timely and precise traveler information, thereby confirming its potential as a feasible solution for enhancing traveler communication services. During the testing phase, the prototype device consistently relayed emergency messages with minimal packet loss and the experimental results obtained from our LoRa-enabled prototype device exhibit a remarkable success rate of 99.5% for emergency communication.

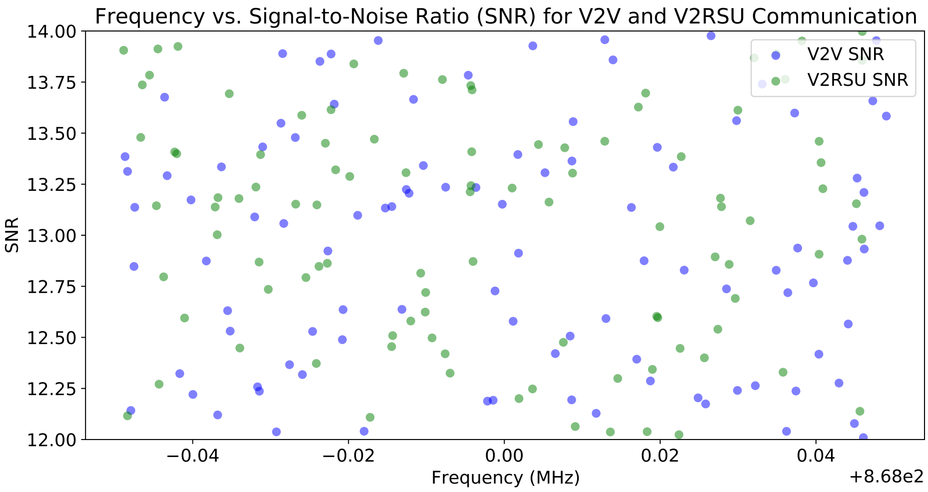

Figure 8: SNR at 868 MHz for V2V and V2RSU communication is being measured for our prototype using LoRaWAN technology.

The high success rate of LoRaWAN technology in crucial scenarios highlights its durability and resilience, ensuring persistent and trustworthy communication. Ensuring that vital information was effectively transmitted to its proper recipient on almost every occasion. High levels of performance are crucial in instances when timely and accurate communication can significantly affect response time and overall safety for travelers.
iii)**Successful transmission of the transmitted message:** Figure 9 depicts the success rate of message transmission between two vehicular nodes employing LoRa (Long Range) modules as the communication medium. The data illustrated in the graph indicates a high degree of reliability in message transmission, revealing that, on average, 99.45% of messages were successfully sent between the nodes.
The outstanding performance of the LoRa modules indicates their efficacy for vehicle communication, especially in tough circumstances where motion, interference, or impediments may affect wireless transmission. Attaining an average delivery rate of 99.45% signifies negligible message loss or failure during transmission, demonstrating LoRa's resilience in sustaining connectivity and facilitating data exchange in automotive networks. This performance level renders LoRa a feasible choice for applications necessitating reliable communication, including V2V systems, intelligent transportation networks, and other vehicular communication contexts, where consistent and dependable data exchange is essential for safety, coordination, and efficiency.

6 Conclusion

This paper presents the implementation of LoRaWAN for traveler informatics, facilitated by connected vehicles, which signifies the advancement of communication infrastructure in crucial situations. The suggested system's durability, low power consumption, cost-effectiveness, and integration capabilities make it an innovative approach for increasing efficiency and effectiveness for boosting traveler safety. In times of emergency, it is essential to establish reliable and trustworthy communication. Benefits of LoRaWAN include reduced MAC control messages, resulting in reduced energy usage and latency.
The proof-of-concept for a traveler informative system that can successfully broadcast

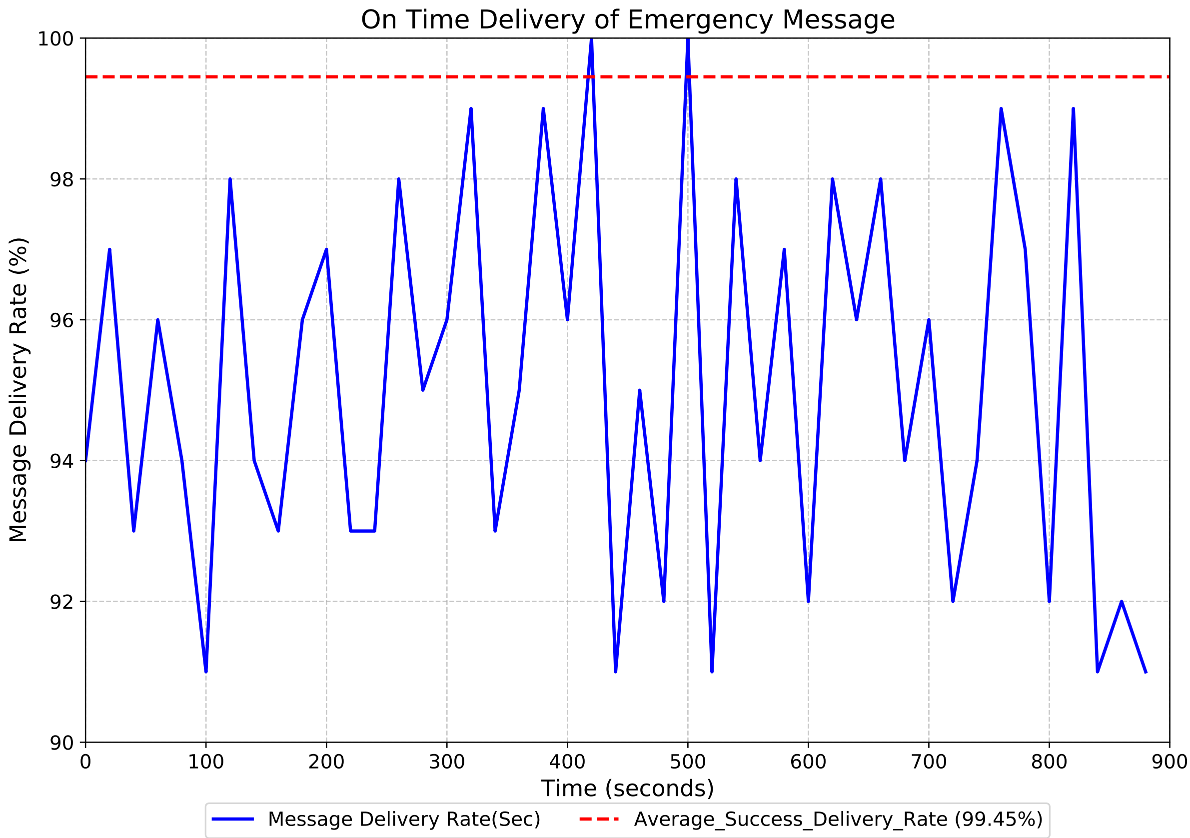

Figure 9: Successful transmission of transmitted message

real-time position, speed, and direction data of vehicles to travelers has been accomplished. This system, which was created to notify travelers in case of possible crashes or real accidents, showcased efficient communication through the utilization of LoRa hardware modules that can be installed in automobiles. The data transfer involved the use of a LoRaWAN gateway functioning as an RSU to connect to TTN and an application-end server dashboard. The RSSI and SNR values exceeded the acceptable criteria, demonstrating a notable level of response efficiency in the findings.
The efficacy of LoRaWAN in managing the low-power, long-range communication requirements that are typical of emergencies is also underscored by the near-perfect success rate. These results not only confirm the technical capabilities of our prototype but also showcase its practical usefulness in real-world situations, thereby opening the possibility for its incorporation into wider traveler informative services. These data's dependability can foster more confidence in the system, facilitating its adoption and deployment.

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