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Design and Integration of the LoRa Protocol for V2X Networks a prototype for enhanced V2V communication and sensing

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Abstract: *Vehicle-to-Everything (V2X) communication is a key enabling technology for intelligent transportation systems, providing vehicles with the capability to exchange information with other vehicles, infrastructure, pedestrians, and network services. Conventional V2X technologies provide high data rates and low communication latency but may face limitations in terms of communication range, deployment cost, and energy consumption, particularly in infrastructure-constrained environments. This paper presents the design and integration of a Long Range (LoRa)-based communication protocol for V2X networks, with particular emphasis on Vehicle-to-Vehicle (V2V) communication and sensing applications. A prototype architecture is developed using LoRa transceiver modules, embedded controllers, and vehicle-mounted sensing units. The proposed system enables vehicles to periodically exchange information such as vehicle identification, position, speed, direction, distance, and detected environmental conditions. A lightweight communication framework is implemented to reduce packet overhead while maintaining reliable information exchange over long distances. The prototype integrates sensing and communication functions to provide early awareness of approaching vehicles and potentially hazardous conditions. The proposed architecture is particularly suitable for low-data-rate safety messages, rural roads, blind intersections, parking areas, and other environments where conventional V2X infrastructure may be unavailable. The study demonstrates the feasibility of integrating LoRa into V2X systems and establishes a prototype platform for further investigation of range, packet delivery ratio, latency, energy consumption, scalability, and mobility performance.*

Keywords**:** *LoRa, V2X, V2V, Internet of Things, Intelligent Transportation Systems, Wireless Communication, Vehicle Sensing, LPWAN, Smart Transportation.*

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I. Introduction

The rapid development of connected and intelligent transportation systems has created requirements for reliable communication between vehicles and their surrounding environment. Vehicle-to-Everything (V2X) communication enables vehicles to exchange information with other vehicles, roadside infrastructure, pedestrians, and cloud-based transportation services. Among the different V2X communication modes, Vehicle-to-Vehicle (V2V) communication is particularly important for improving road safety because it allows vehicles to share information about their location, speed, direction, braking conditions, road hazards, and other safety-related events [1][2].

Existing V2X solutions commonly utilize technologies such as Dedicated Short-Range Communications (DSRC), Cellular-V2X (C-V2X), Wi-Fi-based communication, and cellular networks. These technologies can support high data rates and relatively low communication latency. However, their deployment may require specialized infrastructure, cellular coverage, or comparatively expensive communication hardware. Furthermore, some transportation environments require communication over longer distances while transmitting only small amounts of data [3][4].

Long Range (LoRa) communication provides an attractive alternative for low-data-rate vehicular applications. LoRa is designed for long-range wireless communication with low power consumption and high receiver sensitivity[5]. Its characteristics make it potentially useful for exchanging compact safety messages between vehicles, especially in areas where high-bandwidth communication is unnecessary[6][7]. This work focuses on the design and integration of a LoRa-based communication protocol for V2X networks. A prototype is developed to demonstrate V2V communication and sensing capabilities. The proposed system combines vehicle-mounted sensing devices, an embedded processing unit, and a LoRa transceiver. Sensor information is converted into structured V2V messages and transmitted wirelessly to neighbouring vehicles.

II. Problem Statement

Conventional V2X systems can provide high-performance vehicular communication but may require costly infrastructure, cellular connectivity, or dedicated communication equipment. In rural environments, temporary transportation deployments, campus roads, parking areas, blind intersections, and infrastructure-limited locations, continuous high-bandwidth connectivity may not be available.

The problem addressed in this work is a low-power, long-range LoRa communication system to be designed and integrated with vehicle sensing capabilities providing reliable V2V information exchange for safety-oriented V2X applications. The proposed system aims to transmit compact vehicle sensor information between neighbouring vehicles while maintaining a practical balance between communication range, packet size, energy consumption, and latency.

III. System Architecture

The proposed system consists of multiple connected vehicles, each equipped with a sensing and communication unit. Each vehicle contains a Microcontroller/embedded processor, LoRa transceiver, a GPS/GNSS module, Speed measurement interface, a Distance/proximity sensor, An Environmental sensors, a Display or warning indicator and a Power supply as shown in Figure 1. The vehicle periodically collects its current state and generates a V2V communication packet.

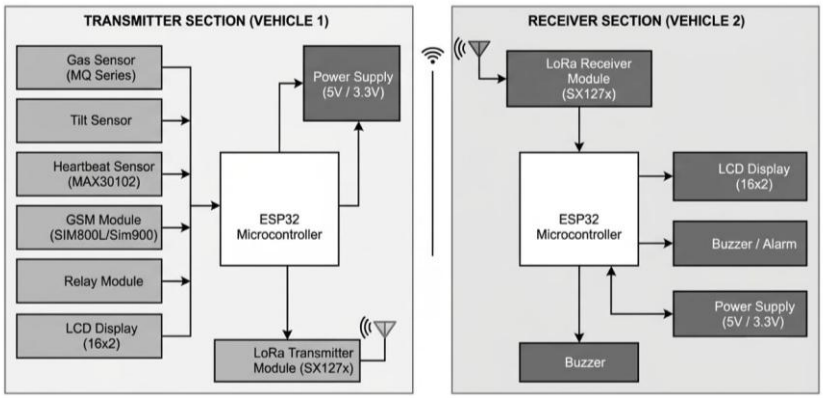

Figure 1. Block Diagram of V2X System Architecture

The system is divided into five major layers namely Sensing, Processing, Communication, Decision and Application Layer for design and development of the system.

Sensing Layer: The sensing layer is responsible for collecting essential information of the vehicle and its conditions in surrounding environment. This is obtained by monitoring variety of key parameters, including the vehicle ID, latitude, longitude, speed, direction, and acceleration. Additionally, it tracks the distance from nearby obstacles, temperature, road and environmental conditions, and also the vehicle's emergency status.

Processing Layer: The embedded controller is responsible for processing incoming sensor information and converting it into a compact communication packet. This process involves several key functions, including sensor data acquisition, unwanted data filtering, vehicle's state estimation, and packet generation. Additionally, the controller is responsible for duties like message transmission control, processing of received messages, and also critical hazard detection in the process.

Communication Layer: The LoRa module facilitates wireless data communication between the vehicles. It has to ensure reliable connectivity, packet transmission and reception, device addressing, message identification, error checking, and communication scheduling.

Decision Layer: The received information is analyzed to determine whether a safety event exists. For example, if Vehicle A detects that Vehicle B is approaching at a relatively high speed and the distance between the vehicles is decreasing, the system can generate a warning.

Application Layer: This layer is responsible for presenting detected information directly to the driver through various output and interface channels. To deliver clear and timely alerts, it utilizes an LCD or OLED display, a buzzer, and an LED indicator. Furthermore, the information can be integrated across a mobile interface and the vehicle's dashboard, with potential for expansion into future cloud and edge platforms.

IV. LoRa-Based V2V Communication Protocol

A lightweight protocol is proposed to reduce the amount of data transmitted through the LoRa link.
A typical message can be represented as:
<HEADER><VEHICLE_ID><LAT><LON><SPEED><DIRECTION>
<DISTANCE><STATUS><TIMESTAMP><CRC>
An example of a conceptual packet is:
V2V | V001 | 17.3850 | 78.4867 | 42 |
NE | 85 | NORMAL | T001 | CRC
where:

- **V2V** = Message type
- **V001** = Vehicle identifier
- **LAT/LON** = Position
- **SPEED** = Vehicle speed
- **DIRECTION** = Direction of movement
- **DISTANCE** = Estimated distance
- **STATUS** = Vehicle condition
- **TIMESTAMP** = Message-generation time
- **CRC** = Error-detection information

The actual implementation can encode these fields into a binary packet to reduce packet length and transmission time.

The proposed communication procedure consists of the following steps:
Step 1: Sensor Acquisition: The vehicle collects sensor and positioning information.
Step 2: Data Processing: The embedded controller filters and processes the collected information.
Step 3: Message Generation: The processed information is converted into a V2V packet.
Step 4: LoRa Transmission: The packet is transmitted through the LoRa transceiver.
Step 5: Message Reception: Neighbouring vehicles receive the packet.
Step 6: Packet Validation: The receiving controller verifies the packet structure and integrity.
Step 7: Vehicle-State Analysis: The received vehicle information is compared with the local vehicle state.
Step 8: Safety Decision: If a potential collision or hazard condition is identified, the warning mechanism is activated.
Step 9: Driver Notification: The driver receives an audio, visual, or dashboard warning.

The prototype can estimate the relative risk between two vehicles using their position, speed, direction, and distance information. A basic distance-based warning mechanism can be defined as where is the current estimated distance between vehicles and is the predefined safety distance. A more advanced implementation can estimate **Time-to-Collision (TTC).** A warning can be generated when the threshold can be configured according to the application and driving conditions. This mechanism can be extended using GPS coordinates, inertial sensors, vehicle speed, and trajectory prediction.

V. Hardware and Software Implementation

A prototype implementation of the proposed system may use the following hardware components presented in Table 1 further this is for demonstration purpose but for actual implementation they may vary.

Table 1. The components required for prototype implementation

Component	Function
Microcontroller	Data processing and protocol execution
LoRa Transceiver	Long-range wireless communication
GPS/GNSS Module	Position and time information
Ultrasonic/ToF Sensor	Distance measurement
Accelerometer/IMU	Motion and acceleration measurement
OLED/LCD	Driver information display
Buzzer/LED	Safety warning
Battery/Power Supply	System power

The software architecture consists of embedded firmware and optional monitoring software. The Embedded firmware performs several functions at a determined period as shown in the flow chart below:

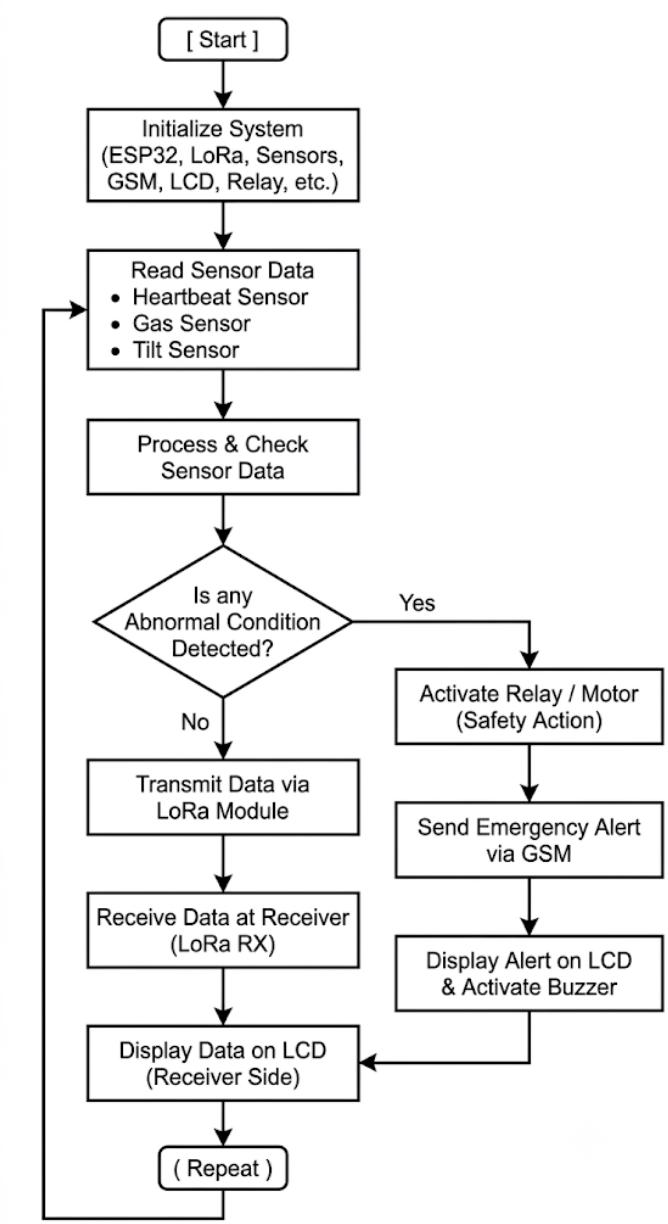

Fig 2: The firmware flow chart

The implementation can be developed using an embedded programming environment appropriate to the selected microcontroller. The prototype should be evaluated using controlled experiments involving two or more LoRa-enabled vehicle nodes. The evaluation can include the following test scenarios.

Scenario 1: Static Communication: In this scenario, two nodes are positioned at different distances while stationary. The evaluation measures key parameters such as the communication range, RSSI, SNR, and packet delivery ratio.

Scenario 2: Vehicle-to-Vehicle Communication: During this scenario, two mobile nodes move toward and away from each other. The performance is assessed by measuring the packet delivery ratio, communication latency, RSSI, SNR, and message reception rate.

Scenario 3: Obstacle/Non-Line-of-Sight Communication: Vehicles communicate in environments containing buildings, trees, or other obstacles. This setup is designed to evaluate the effect of the propagation environment on connectivity and reliability.

Scenario 4: Safety Warning: In this test, two vehicles approach each other while transmitting their position and speed information. The system determines whether the estimated TTC falls below the configured threshold.

The following metrics should be used to evaluate the prototype:

Packet Delivery Ratio: The packet delivery ratio is evaluated based on the relationship between successfully received packets and total transmitted packets.
Packet Loss Ratio: The packet loss ratio calculates the proportion of packets lost relative to the transmission volume.
Communication Latency: Communication latency is determined by tracking the time difference between the transmission timestamp (t_t) and the reception timestamp (t_r).
Communication Range: The maximum distance at which valid V2V packets can be exchanged with the required PDR represents the effective communication range.
Energy Consumption: Energy consumption can be estimated by accounting for the system power and the total operating time.

VI. Results and Discussions

The figure below illustrates the Transmission Unit of the proposed system. It consists of multiple components such as Sensors, Sim, LORA module, Mobile device which is used to send/receives a message to authenticate and access the system before the actual application starts.

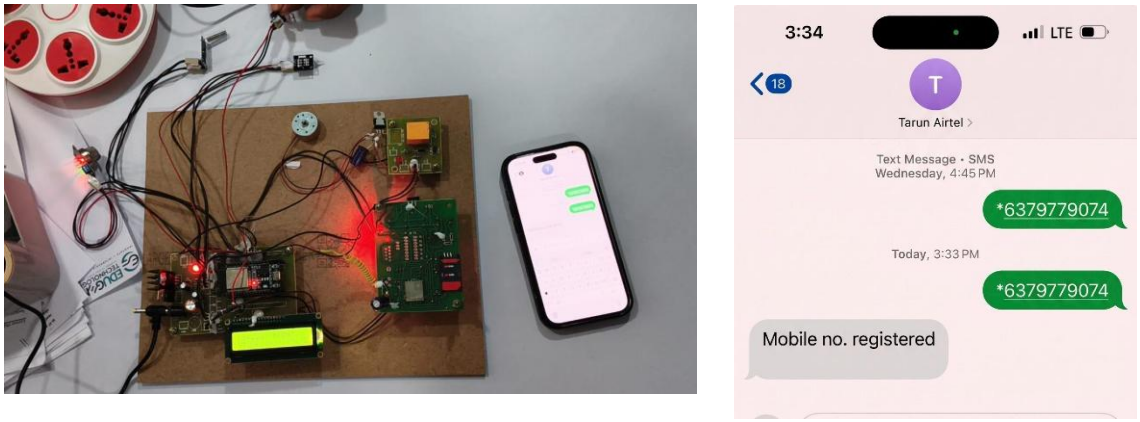

Fig 2: LoRa-Based V2V Communication System is ON Condition

The Figure 3 illustrates the Receiver in ON Condition and before the receiver receives the alert/values from transmission vehicle. The Receiver circuit contains a Buzzer, an LCD to display the Output, a LED light to show the switch in on condition and a LORA receiver module etc,.

The prototype developed, was tested by the hardware setup and the mobile SMS interface is shown in the images above. The results show the inclusion of a sensor and communication unit operated by a microcontroller, an LCD screen to see the local state and a mobile messaging system to get display the data of the sent state.

The experimental setup demonstrates the use of wireless communication based on LoRa for transfer of vehicle-related data between the transmitter and reception devices. The LCD displays the received or processed status visually, and the mobile screen shows text messages related to the monitoring system. These results illustrate in concrete terms how sensor data could be seen locally and sent away.

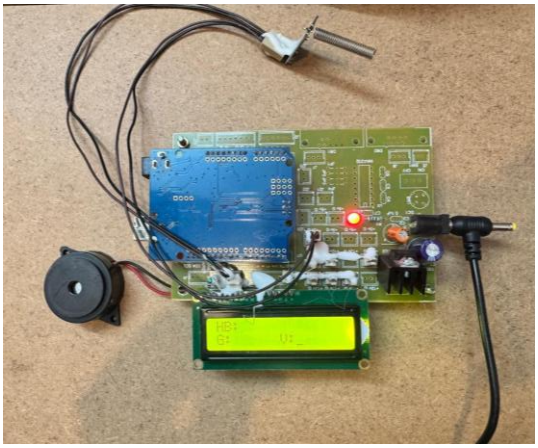

Fig 3: Receiver in ON condition

The experimental image in figure 4 shows the SMS interface to show the messages generated by the monitoring system. The "Mobile no. registered", "HB-0-Gas-ON", "HB-70-Gas-ON", "HB-0-Vib-ON" and "HB-71-Vib-ON" are the visible notifications. These notifications indicate that the system has an interface to register cell numbers and transmit gas sensor and vibration status data. The set of messages means that the system can offer written notifications on certain sensor statuses or reported statistics. Messages on gas indicate that it is ON, messages on vibration indicate that the vibration monitoring system is active. The numeric parts of the messages are sensor readings, IDs or other program information.

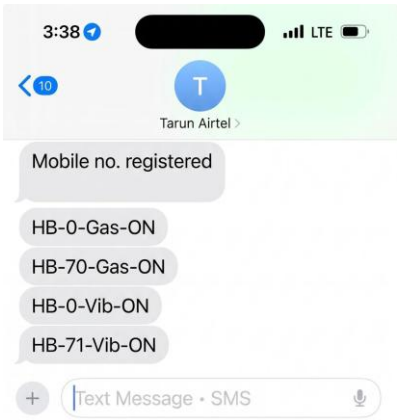

Fig 4: Mobile SMS Output after Transmission of Data from LORA Tx module.

The correct interpretation depends on the firmware running condition. The use of SMS provides an effective way to communicate the monitoring information to a distant person. This facility may be useful in a dangerous scenario for a vehicle as the system is programmed to inform a registered mobile number. However, the displayed messages alone do not provide confirmation of the dependability of the sensors, the time taken for notification distribution or the effective completion of all communication phases is of limitation.



Fig 5: LCD displaying Heart beat, Gas and Vibration values

The above image illustrates the LORA Transmitter Vehicle containing Heart beat, Gas and Vibration values displayed on the vehicle dash board, this means that the heart beat is monitored, there are No gas emitted from the vehicle, and the vibration is ON. These readings are then transmitted to the receiver end and the output is displayed as shown in image below (figure 6).



Fig 6: Status displayed at the receiver end.

The main observations from the experimental set-up are summarised in the following table. The following table provides the recommended structure for presenting measured results.

Table 2. Experimental observations

Parameter	**Experimental observation**	**Analysis**
Mobile-number registration	Registration confirmation message is visible	Supports the configured mobile notification workflow
Gas monitoring	Gas-related SMS messages show ON; LCD shows OFF	Various states have been recorded. Their timing and triggering conditions must be verified.
Vibration monitoring	Vibration-related SMS messages show ON; LCD shows ON	The vibration status is represented through both messaging and local display interfaces
LCD display	Numerical and sensor-status fields are visible	Enables local observation of system information
Indicator output	Red indicator is illuminated	Confirms an active indicator output, but its precise purpose requires circuit verification
Remote notification	Multiple sensor-related messages appear on the phone	Demonstrates the availability of sensor-related messages in the SMS interface
LoRa communication	Part of the proposed communication architecture	Successful end-to-end LoRa performance requires separate communication tests

The experimental analysis investigates the relationship between communication distance and packet reliability. As the distance between vehicles increases, received signal strength is generally expected to decrease, potentially resulting in lower packet reception reliability. Environmental factors such as obstacles, antenna orientation, interference, and vehicle movement should also be considered.

The prototype is intended primarily for low-data-rate safety and sensing information, rather than multimedia or high-bandwidth V2X applications. Consequently, the suitability of LoRa is assessed according to the specific application requirements rather than directly comparing it with high-throughput V2X technologies.

VII. Advantages and Limitations

The proposed LoRa-based V2V system offers several potential advantages:

- **Long-range communication:** LoRa can support communication over considerably longer distances than many conventional short-range IoT technologies under suitable propagation conditions.
- **Low power consumption:** The communication architecture is appropriate for battery-powered embedded devices.
- **Low-cost prototype development:** Commercially available LoRa modules and microcontrollers can be used.
- **Infrastructure independence:** Direct communication can be implemented without depending entirely on cellular infrastructure.
- **Compact safety messages:** Vehicle state information can be transmitted using small packets.
- **Sensing integration:** Communication and environmental sensing can be combined in a single platform.
- **Scalability for research:** Multiple nodes can be deployed to investigate multi-vehicle communication scenarios.

Despite its advantages, LoRa also presents limitations for V2X applications.

- LoRa is optimized for low-data-rate communication and therefore is not appropriate for applications requiring continuous video, high-volume sensor data, or other bandwidth-intensive services.
- Communication latency and channel access behavior must be carefully considered for safety-critical applications. LoRa-based systems should therefore be treated as complementary communication mechanisms unless their performance has been rigorously validated against the latency and reliability requirements of the intended safety application.

- Increasing the number of vehicles sharing the same channel can result in packet collisions and reduced communication reliability.
- Vehicle mobility introduces rapidly changing network conditions, making protocol design and experimental evaluation important for practical deployment.

VIII. Conclusion

The paper presents the design and integration of a LoRa-based communication framework for V2X networks, focusing on Vehicle-to-Vehicle communication and sensing. The proposed architecture integrates embedded controllers, vehicle sensors, positioning modules, and LoRa transceivers to facilitate the exchange of compact vehicle-state and safety-related information. Unlike conventional high-bandwidth V2X systems, the proposed architecture targets applications where long-range, low-power, and low-data-rate communication are more important than high throughput. The prototype provides a foundation for investigating vehicle proximity detection, hazard notification, position exchange, and collision-awareness applications. It demonstrates the feasibility of using LoRa as a complementary communication technology for selected V2X scenarios. However, comprehensive field testing is required to quantify communication range, packet delivery ratio, latency, scalability, energy consumption, and mobility performance. Need to focus on adaptive communication protocols, multi-vehicle experiments, intelligent collision prediction, security mechanisms, and hybrid LoRa–5G/C-V2X architectures for better optimizations and real-time estimations.

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