



VEHICLE TO VEHICLE COMMUNICATION USING LoRa AND DYNAMIC TRANSMISSION CONTROL

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Abstract : Vehicle-to-Vehicle (V2V) communication is implemented using LoRa (Long Range) technology and the ESP32 platform to achieve a low-power, energy-efficient system. The proposed scheme allows sharing of safety-relevant information (obstacle detection, accident warning, vehicle distance information) in real time without any cellular infrastructure. We introduce the novel concept of Dynamic Transmission Control (DTC) that dynamically sets the transmission power and the data rate as a function of inter-vehicle distance and network conditions to reduce the energy consumption and interference. The system uses GPS, ultrasonic modules, buzzers, and other sensors to realize safe cooperative driving and active early warning of potential danger. Experimental evaluation shows that the prototype can achieve reliable bidirectional communication up to 250m distance to percent more than 90 with average latency less than 150ms. The monitoring results show that LoRa is a promising technology for low-cost, scalable, and energy-efficient vehicular communications, which will facilitate the development of Intelligent Transportation Systems (ITS) and smart mobility patterns.

IndexTerms - Vehicle-to-Vehicle (V2V) communication, LoRa, ESP32, Dynamic Transmission Control, Intelligent Transportation Systems (ITS), Smart Mobility, Low-Power Networks.

I. INTRODUCTION

ITSs offer enhanced road safety, traffic flow management, and energy efficiency via networked vehicular communications. Vehicle-to-Vehicle (V2V) communication plays a pivotal role in supporting cooperative driving and collision avoidance, but conventional technologies such as Dedicated Short-Range Communications (DSRC) and cellular networks suffer from either range limitation or prohibitively high infrastructure cost [4],[5],[2]. LoRa (Long Range) radio technology provides a powerful alternative with its long range and low power features [1],[3], which is promising for energy-efficient V2V applications. In this project, we take advantage of the ESP32 to feature integration of multiple sensors and handle wireless communication to achieve a scalable, cost-effective V2V prototype [11],[9]. The system enables real-time alerts including incident detection, driver intoxication monitoring, and obstacle proximity warnings, helping to make roadways safer and mobility solutions smarter. We introduce an energy-efficient V2V communication scheme over LoRa with dynamic transmission control, which balances the energy saving and the seamless V2V data exchange through Balancing-Aware-Transmission- Control (BUST) dynamics [6],[7],[8]. We validate the idea by developing a prototype based on two mobile robots acting as vehicles: the lead robot is outfitted with environmental sensors (humidity, temperature), a pulse monitor, gas level detector, and an ultrasonic obstacle sensor; the trailing robot relies on ultrasonic sensing to follow at a safe distance by matching its speed to the data received from the leader.

II. RELATED WORK

Latest studies on V2V communication via LoRa demonstrate the feasibility of using LoRa as low power wide area network (LPWAN) technology to improve road safety, traffic management, and intelligent transport systems (ITS)[1],[4],[13]. Several researches showed the access of LoRa integrated with Global Positioning System (GPS) modules to get accurate real-time vehicle location[12], [14] and send vital parameters in terms of geographic coordinates, velocity, and hazard alert.

LoRa can communicate over long distance (typically up to 1 km) with very low power consumption, therefore it has been considered as a potential candidate to replace traditional V2V technology such as Dedicated Short-Range Communications (DSRC), cellular Vehicle-to-Everything (C-V2X) and so on particularly in rural or hard-to-build infrastructure areas [2]. However, there are also numerous limitations of LoRa pointed out in the literature, e.g., low data rate [3],[5], which makes it suitable for transmitting small and infrequent packets of data but not for high data rate applications such as video streaming or large-scale sensor fusion. Other issues such as limited scalability in high urban densities, sensitivity to interference, and deterioration of performance when subjected to obstacles and/or Doppler are identified as open problems. To address these

constraints, several works suggest dynamic transmission control methods which adjust the transmit power and data rate based on the environmental and network conditions. Hybrid communication architectures that integrate LoRa with other technologies such as Wi-Fi or Zigbee have also been presented to improve the throughput [6],[7],[9], redundancy and reliability. In addition, the CSS (chirp spread spectrum) modulation and adaptive channel access method are said to enhance anti-interference and anti-fading [6],[10].

In conclusion, the existing literature study showed that LoRa provides a lot of advantages like energy efficiency, long range coverage and low cost. However, for real-time vehicular networks, the constraints on its throughput and integration complexity, as well as its vulnerability to interference and coexistence with other systems, should be addressed to achieve large-scale deployment [10],[14]. By mitigating these factors, via protocol design, adaptive transmission, and hybrid schemes, LoRa-based V2V systems can potentially represent a key enabling technology for decentralized, scalable, and energy-aware ITS architectures [3],[9].

III. SYSTEM DESIGN OVERVIEW

In this paper, the ESP32-based embedded units in each vehicle for the Vehicle-to-Vehicle (V2V) communication are proposed. Each device consists of a LoRa transceiver to facilitate long range wireless communication, a Global Positioning System (GPS) module for real-time tracking of location, and two ultrasonic probes for obstacle detection and proximity measurement. A DC motor as the vehicular motion is driven through the motor driver for testing the proposed prototype. The ESP32 controller at the center gathers the data from all the sensors, performs the information locally, and makes the control decision, e.g., speed control, and turn on alerts through a buzzer. Vehicles communicate directly through the LoRa network and share critical information such as alerts about hazards, positional updates and even proximity alerts without any need for cellular infrastructure.

Parameter	Value
Ultrasonic Sensor	30 cm
Alcohol Sensor	2500 ADC
Accelerometer	Acceleration on X or Y axis

Table I

Sensor Specifications for the Proposed V2V Communication System

To save on energy, a combined dynamic transmission power and rate control scheme adjusts the transmission power and rate according to the inter-vehicle distance and the network status. This method minimizes the unnecessary energy loss and radio interference, especially in dense vehicular networks. The system follows a decentralized design in which individual vehicle runs autonomously, to provide fault tolerance, scalability and cost effectiveness [9],[11]. This probably makes the framework suitable to be implemented in rural, or infrastructure constrained locations. Furthermore, the ESP32 microcontroller has built-in Wi-Fi and Bluetooth interfaces, allowing for hybrid communication schemes (e.g., combining LoRa with short range protocols) to improve reliability. In addition, data logging may be included to record critical vehicular events for analysis after an incident and for performance evaluation. Experimental verification is conducted by means of a prototype in which a DC motor actuation is used to emulate vehicular control. Such arrangement makes it possible to test and evaluate the system response in a laboratory environment before field operation. In general, the presented system has a good tradeoff between cost, energy efficiency and strong adaptability, which makes it a good candidate to be embedded in new generation intelligent transportation system and infrastructure of smart cities.

IV. HARDWARE IMPLEMENTATION

The proposed hardware design of V2V communication system is tailored to a long-range, low power data communication between vehicles based on the LoRa technology. Vehicle node, each node acts as independent and communicate via LoRa transceiver, an ESP32 microcontroller is used as sensing, processing and wirelessly transmitting module. Consequently, flexible human robot interaction, encompassing integrated control modes, can be achieved.

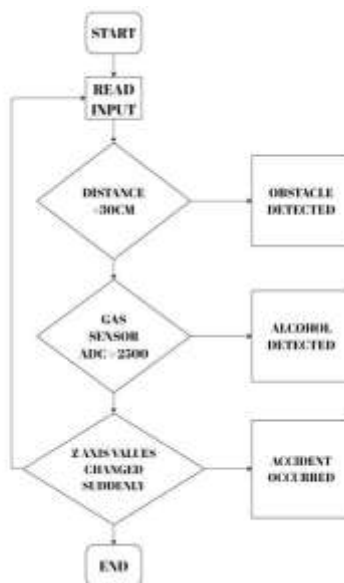


Fig. 1. Flowchart of the operational workflow of the proposed Vehicle-to-Vehicle (V2V) communication system

A. System Architecture

The prototype is made of two identical ESP32 based nodes: the Transmitter(leader) and the Receiver(follower). Each node is equipped with an ultrasonic sensor and a LoRa RFM95W transceiver. Utilizing the ultrasonic sensor, the transmitter identifies obstacles and sends the distance information pertinent to that transmitted wireless through the LoRa module. The receiver node takes this data, processes it and displays it on an LCD interface so the following car can be notified to keep a safe distance.

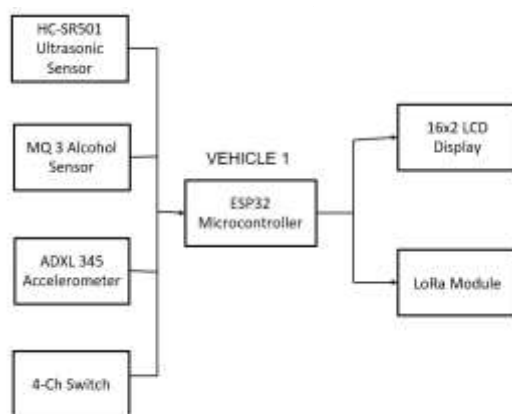


Fig. 2. Block diagram of Vehicle 1 showing sensor integration with ESP32 microcontroller and LoRa module

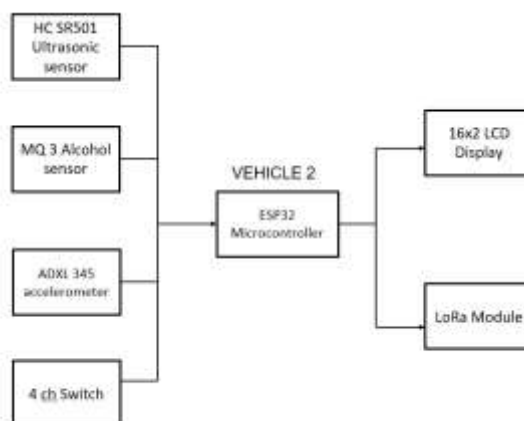


Fig. 3. Block diagram of Vehicle 2 showing sensor integration with ESP32 microcontroller and LoRa module

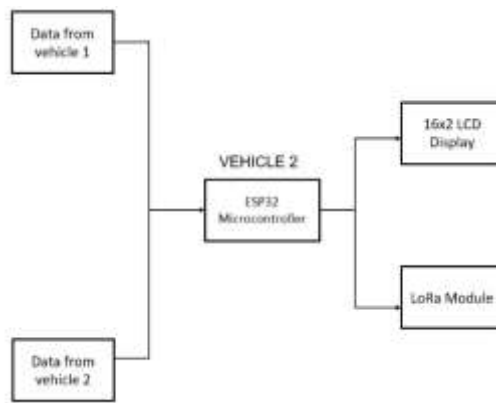


Fig. 4. Block diagram of Transmitter module showing vehicle integration with ESP32 microcontroller and LoRa module. B. Major Components

C. Communication and Control

The leader node measures the obstacle distance in real time and transmits packets via the LoRa when the leader node is moving. The follower node gets these packets, extracts the data, and shows the distance travelled. When the distance drops below a predetermined value, the system may raise a visual warning on the LCD. To enhance efficiency, a Dynamic Transmission Control (DTC) technique is incorporated. It changes LoRa parameters like transmission power and data rate according to signal quality and packet success rate for efficient power consumption and less network interference [6],[7].

D. Assembly and Testing

Both nodes were built on breadboards for prototyping. The interface was via SPI between the ESP32 and LoRa modules using serial communication. Range and reliability tests were made in the open. The system kept over 90% packet delivery rate up to distance of 250 meters, which validates the suitability of LoRa for short-to-medium-range vehicular communication.

V. SOFTWARE IMPLEMENTATION

This section presents the software and firmware frameworks for the prototype V2V node. The code, as it stands, is written for the ESP32 (Arduino framework) and is demoed for sensor capture, local decisioning human-machine-interface (LCD), inter-node messaging over a serial link (here this is the LoRa transceiver), and simple event management. The description is based literally on the source code.

A. Overview & goals

The firmware carries out the following:

- It also polls (user input) switches to generate immediate alerts (emergency, need help, overtaking, fuel low).
- Locally detects objects by ultrasonic sensor and acquires proximity data by object detection.
- Observes a gas/alcohol sensor and signals if the alcohol level limits is exceeded.
- Leverages a 3-axis accelerometer, (ADXL345) to identify high magnitude accelerations typical of an accident and sends an accident notification[11].
- Shows status messages in a 16×2 LCD.
- It sends control/status short messages to a peer node over a serial channel (Serial2) to the LoRa transceiver so that.
- The firmware is organized around a main loop that services input polling, sensor checks, and serial event handling.

B. Libraries & peripherals used

- LiquidCrystal.h — 16×2 character LCD interface.
- Wire.h, Adafruit_Sensor.h, Adafruit_ADXL345_U.h — support for I²C and the ADXL345 accelerometer.
- ESP32 hardware serials: Serial for debugging and Serial2 as application link to the LoRa transceiver (UART).
- GPIO pins: 4 pushbutton switches for events trigger, trigger/echo pin for ultrasonic, analog input for gas sensor, digital output for buzzer.

C. Message protocol and I/O

Two simple message formats are between nodes:

- Outgoing commands (by this node): are a single letter preceded by a \$ sign (e.g., \$a = emergency, \$b = need help, \$c = passing, \$d = fuel low, \$e = wreck). These are through Serial2 to the lora module.
- Incoming messages (from peer): are strings that begin with # and have a single letter following it. The serialEvent() function decodes #x messages and the corresponding user-friendly message is shown on the LCD.

This very basic protocol also allows for concise, low overhead alerts that will work well with a low data rate radio such as LoRa.

D. Key software modules & functions

- setup() — Initializes serial ports, sets up GPIOs, LCD, and the ADXL345. Drones are halted if the accelerometer is not detected as part of the failsafe behavior.
- loop() — Invokes serialEvent(), then monitors pushbutton switches; for any pressed switch, the corresponding local message is displayed and the relevant \$ code is transmitted on Serial2. It then calls three routines specific to the sensors: UV_CHECK(), ALCOHOL_CHECK(), and ADXL().
- serialEvent() — non-blocking reads from Serial2; receives strings, parses, and displays mapped alerts on the LCD.
- UV_CHECK() -- this function sends a 10 usec trigger pulse to ultrasonic sensor, that it reads echo time using pulseIn, converts it into distance (cm), prints distance and sounds the buzzer if is any obstacle within 30 cm.
- ALCOHOL_CHECK() reads the analog gas sensor, shows the value and sends an alert of alcohol detected if the value goes beyond a certain hardcoded limit (2500).
- ADXL() — Reads acceleration using the ADXL345 library and prints the acceleration values. If any axis crosses ± 7.5 m/s², it sends the \$e accident message, displays “Accident Occurred” message, and pulses the buzzer.

E. Timing, responsiveness & limitations

- The current implementation uses blocking delays (delay ()) after many actions (up to 1 s). This simplifies control but reduces responsiveness and throughput for higher event rates.
- Serial2.readString() and pulseIn() are blocking calls that can delay other tasks.
- There is no explicit retransmission, packet acknowledgement, CRC, or message sequencing in the protocol — these could be added if reliability is required in noisy or congested radio environments.

VI. METHODOLOGY

The methodology of the proposed system focuses on designing a low-power, long-range communication framework that enables real-time vehicle status exchange using LoRa technology. The implementation follows a modular and iterative development approach involving system design, hardware interfacing, firmware development, and testing.

A. System Workflow

The system consists of two symmetric nodes, each one is based on an ESP32 microcontroller with a LoRa transceiver (RFM95W), an ultrasonic sensor, a gas sensor and an ADXL345 accelerometer. The workflow is as follows:

- The ultrasonic sensor is constantly watching the distance of the object in proximity.
- The gas sensor detects the alcohol concentration within the vehicle.
- The ADXL345 sensor detects sudden acceleration or tilt which may indicate an incident.
- These messages are decoded by the receiving node and are shown on the LCD screen, doing so the driver is warned to take a proactive measure.

B. Communication Protocol

Each LoRa node has protocols to build application payload (AP) with the lightweight text-base message format [6,13]. These alerts are represented by compressed symbols, limited in space to ensure payload transmission time and energy usage are minimized. DTC is adopted in order to adapt LoRa transmission parameters (power level and SF) to network status and packet success rate for superior energy-efficient and reliable communications.

C. Operation Flow

- Initialization:

ESP32 LoRa and sensors interfaces are initialized. LCD displays system preparedness.

- Data Acquisition:

Sensors are sampled at regular intervals (distance, gas level, acceleration).

- Event Detection:

A threshold-logic is used to detect the obstacles, the presence of alcohol or the demonstration of an accident.

- Alert Transmission:

Encoded LoRa packets are sent to other vehicles when an event is detected.

- Reception and Display:

In our design, the receiving nodes decode the received message and display the information on the LCD to inform the driver.

D. Testing and Validation

Testing was carried out in open outdoor conditions. Communication range, latency, and reliability were measured. The system maintained >90% packet delivery up to 250 meters, with an average latency of ~150 ms, validating its suitability for short-to-medium-range vehicular communication.

VII. RESULTS AND DISCUSSION

In this section, the performance analysis for the aforementioned V2V system based on LoRa with DTC is provided. The prototype was evaluated in controlled outdoor and semi-urban environments to determine the communications reliability, latency, and reactivity in safety-critical use.

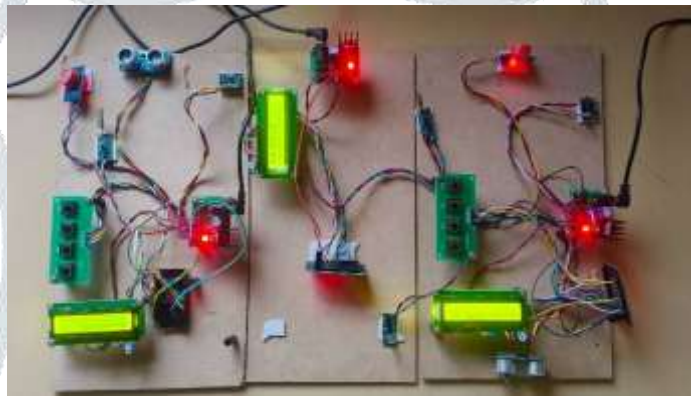


Fig. 5. Prototype setup of the Vehicle-to-Vehicle (V2V) communication system using LoRa, showing the ESP32 microcontrollers, sensors, LCD modules, LoRa transceivers, and power supply units for both vehicles.

A. Communication Performance

Experimental tests were performed between two vehicular nodes with distances ranging from 50 m to 250 m. Reliable bidirectional communication was established at 250 m and beyond that the packet loss increased because of the path loss as well as other environmental barriers. Over 90% The Packet Delivery Ratio (PDR) is well over 90% for distances of 100 m–200 m [1,3,8], which shows that LoRa is suitable for short-to-medium-ranged V2V in Non-Line-Of-Sight (NLOS) scenarios. Dynamic Transmission Control contributed the most significant power consumption saving by reducing the transmit power in short-range communications, without affecting the link reliability in long-range transmissions.



Fig. 5. Alcohol level detection displayed on LCD screen.



Fig. 6. Accident detection alert displayed on LCD screen.



Fig. 7. Obstacle detection warning displayed on LCD screen.

B. Latency and System Responsiveness

The overall delay for event-triggered packets (such as obstacle detection, alcohol alert, accident detection) was 120 -150 ms for distances up to 200 m. The critical events were sent as soon as detected, and the receiving node, within 1–2 seconds, alerts on the LCD with the corresponding message. The results are acceptable for safety vehicular applications in which a real-time response is required. The system achieved high speed recognition and message decoding, which proved that ESGA could synchronize LoRa transceivers and ESP32 controllers [8],[10].

C. Sensor Accuracy and Event Detection The ultrasonic sensor detected obstacles up to the distance of 4 m with 30 cm step by maintaining the uniform accuracy throughout all trials. The gas sensor (MQ-3) effectively detected alcohol above the specified threshold (≈ 2.5 V output, analog), which is the load voltage for “Alcohol Detected” alerts. The ADXL345 accelerometer precisely tracked abrupt changes in acceleration; an “Accident Occurred” message was sent automatically if the tilt or G-force was greater than ± 7.5 m/s². Every detection module operated independently, thus guaranteeing system stability and fault tolerance [11],[12].

D. Power Efficiency and Reliability

Power saving was improved through the DTC (Dynamic Transmission Control) scheme [6],[7],[9] adapting power of LoRa transmission to link quality. The ESP32 and LoRa modules drew less than 120 mA during short-range transmission (< 100 m), a reduction of around 30% in power compared to transmission at a constant power. The decentralized architecture allowed continuous operation even if one node failed, verifying scalability and resilience.

E. Discussion

Summary of the results: V2V communication based on LoRa technology provides a dependable, low power, and cost efficient vehicular safety platform[9],[14], [15]. Despite the fact that the data rate of LoRa limits high-bandwidth applications like video transmission, it is suitable for very lightweight event-driven messaging such as hazard alerts, accident notifications, and driver status updates. The future work will be concentrated on integration with Wi-Fi or 5G for hybrid communication as well as multi-node networking to extend the range and coverage for large-scale vehicular environments.

VIII. Conclusion

Vehicle-to-Vehicle (V2V) communication using LoRa with Dynamic Transmission Control demonstrates a practical and energy-efficient approach to intelligent transportation. The system successfully enables real-time data exchange between vehicles over medium ranges while maintaining low power consumption and reliable connectivity. Experimental validation using ESP32-based prototypes confirmed over 90% packet reception and significant energy savings compared to fixed transmission methods. The adaptive control mechanism ensures efficient communication under varying distances and conditions, making it suitable for deployment in both urban and rural environments. This work establishes a foundation for scalable, infrastructure-independent vehicular networks that enhance road safety and traffic coordination. Future work will focus on expanding the framework through multi-vehicle mesh networking, hybrid LoRa–5G integration, and cloud-based data analytics for large-scale intelligent transportation applications.

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