BANSILAL RAMNATH AGARWAL CHARITABLE TRUST'S

VISHWAKARMA INSTITUTE OF TECHNOLOGY

(An Autonomous Institute affiliated to Savitribai Phule Pune University)

AutoCluster: IoT-Based Vehicle Coordination Using Dynamic access

CS-B Group -3

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UNDER THE GUIDANCE OF

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CERTIFICATE

This is to certify that the Course Project titled AutoCluster: IoT-Based Vehicle Coordination Using Dynamic accesssubmitted by **Group No.- 21 of Computer Science Div- B** is in partial fulfillment for Microcontroller and microprocessors Course Assessment. This project report is a record of Bonafide work carried out by above group under my guidance during the academic year 2024-25.

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ABSTRACT

This project presents an IoT-based Vehicle Clustering System that enables real-time communication between multiple cars to enhance road safety and traffic efficiency. The system utilizes NodeMCU (ESP8266/ESP32) microcontrollers and ultrasonic sensors to measure inter-vehicle distance and dynamically form vehicle clusters. A dynamic access point (AP) is established using one of the vehicles as a leader, allowing seamless data exchange between cluster members. The system provides collision prevention, optimized lane management, and real-time notifications via an onboard display. By implementing V2V (Vehicle-to-Vehicle) communication, the proposed solution enhances intelligent transportation systems (ITS) and autonomous vehicle coordination.

Section I] INTRODUCTION

The integration of electronics with wireless communication has opened the doors to a multitude of intelligent, interactive systems. The Internet of Things (IoT), a leading technological paradigm, has empowered devices to sense, communicate, and act autonomously. In this landscape, microcontrollers like the ESP8266 NodeMCU have become essential building blocks for DIY, academic, and industrial projects. This project explores the development of a Wi-Fi-based smart car communication system involving three cars equipped with ESP8266 microcontrollers, ultrasonic sensors, LEDs, and buttons. These cars are not only capable of exchanging information over a wireless network but also intelligently switch their operational roles—between Access Point (AP) and client—based on signal strength and availability. This introduces a degree of autonomy, decentralization, and adaptability that mirrors the dynamic nature of real-world communication systems.

This system was designed with the intention of solving a common challenge in multi-node communication setups—ensuring reliable peer-to-peer communication in a mobile, ever-changing environment. When cars or mobile agents are deployed in a space with no fixed central controller, they must cooperate and take over communication responsibilities dynamically. Hence, in this project, Car 1 begins as the AP, allowing Cars 2 and 3 to connect as clients. However, if Car 1 becomes unreachable (for example, if it moves out of range), the clients analyze RSSI (Received Signal Strength Indicator) values and autonomously decide which car will assume the AP role, ensuring communication continuity. This self-healing, distributed behavior is a key innovation of this project.

To enhance safety and functionality, each car is equipped with two ultrasonic sensors—one at the front and one at the back. These sensors continuously monitor the surroundings and help detect if another object or vehicle is dangerously close. When proximity breaches a defined threshold (e.g., <20 cm), the system activates a "Too Close" warning, which is visually represented through an external LED and also transmitted as a message to connected clients. This feature mimics basic collision-avoidance behavior, often found in modern autonomous vehicles, and adds a practical safety dimension to the communication system.

Beyond reactive distance-based behavior, the system incorporates user interaction through a push-button. When the button is pressed, it sends a predefined message such as "I am overtaking!" to other vehicles in range. This function simulates real-life driving scenarios where one vehicle may need to communicate its intent to others, improving coordination and reducing ambiguity. The button-triggered communication is instantaneous and simultaneously printed to the Serial Monitor and transmitted over Wi-Fi, showing clear responsiveness.

To further aid user understanding and debugging, internal LED indicators are included. The built-in LED (D0 or LED_BUILTIN) lights up when a car becomes an AP, while a small internal LED (e.g., D5) lights up when the car is connected as a client. The external LED (e.g., D6 or D7) is reserved for critical alerts like obstacle detection. These visual cues allow a user to immediately understand the role and condition of each car without referring to a monitor.

The switching between AP and client mode is managed through dynamic RSSI-based logic. Each car starts in client mode, scans for available networks, and measures the RSSI of the known SSIDs corresponding to the other two cars. If a car finds a stronger signal from a peer, it attempts to connect as a client. If no reliable AP is found (e.g., after scanning for 3–5 seconds), the car then switches to AP mode for a brief duration (e.g., 3 seconds), broadcasting its SSID and waiting for others to connect. This back-and-forth toggling between modes mimics decentralized election logic and ensures that one and only one car acts as an AP at any time, maintaining stability in the network.

The project demonstrates not just basic communication but intelligent role management, an essential feature in distributed systems and autonomous networks. By simulating the real-world behavior of mobile agents who must stay in touch, cooperate, and share safety-critical information, the project holds practical relevance in scenarios such as automated traffic management, swarm robotics, and emergency response systems. In real-world deployment, this logic could be extended to fleets of drones, automated delivery robots, or smart vehicles that coordinate using ad hoc wireless networks.

The decision to use the ESP8266 NodeMCU is driven by its affordability, simplicity, and robust Wi-Fi capabilities. It supports both AP and STA modes, making it ideal for this dual-mode behavior. The software implementation is done in the Arduino IDE, utilizing standard Wi-Fi libraries and basic digital I/O. Ultrasonic sensors are interfaced using GPIOs and driven with simple pulse-based logic, while the Serial Monitor helps in debugging RSSI values, distance measurements, button presses, and message logs. No additional hardware like motor drivers or cameras is used here, making the focus purely on communication, sensing, and logic.

Overall, this project combines hardware interfacing (ultrasonic sensors, LEDs, buttons) with networking principles (AP/STA switching, RSSI scanning) and event-based programming (button-press messages, alert signals) to create a coherent and resilient communication system among multiple mobile units. The system is lightweight yet scalable, allowing for more cars or sensors to be added in the future. The simplicity of its logic also makes it an excellent candidate for educational purposes in IoT, embedded systems, and autonomous systems courses.

In conclusion, this project offers a glimpse into the future of cooperative intelligent vehicles. It shows how even with modest hardware and straightforward programming, one can build a responsive, self-organizing, and safety-conscious communication network. With enhancements like GPS, camera streaming, or machine learning models for smarter decision-making, this project could evolve into a real-world prototype for connected vehicle ecosystems. For now, it stands as a powerful demonstration of how distributed logic and wireless communication can be orchestrated for dynamic, mobile IoT applications.

Section II] PROBLEM STATEMENT

In today's rapidly evolving technological landscape, especially within the realm of intelligent transportation systems, the need for efficient, reliable, and cost-effective communication between vehicles has become increasingly important. Vehicles that can interact with one another and make dynamic decisions based on their environment offer significant potential in enhancing road safety, reducing accidents, and streamlining traffic flow. However, building such systems using affordable microcontrollers like the ESP8266 presents several challenges, including managing dynamic wireless communication, detecting surrounding objects, and ensuring timely message exchanges between units.

A core issue in multi-vehicle systems is ensuring continuous and reliable communication. In traditional network configurations, a fixed Access Point (AP) is required to serve all client nodes. But in a moving car environment, the designated AP might move out of range or lose power, disrupting the entire network. To address this, the system must be capable of switching roles dynamically—where any car can become an AP if the current one becomes unavailable. This requires constant monitoring of signal strength (RSSI) and smart decision-making by the clients to disconnect and reconnect based on network quality and proximity.

At the same time, ensuring that vehicles are aware of their surroundings is equally crucial. To prevent collisions, each vehicle must be equipped with sensors that detect obstacles or nearby vehicles. Ultrasonic sensors, due to their low cost and effectiveness at short distances, are ideal for this use case. These sensors can measure the distance in front and behind the car, allowing the system to generate alerts when another vehicle or object comes too close. These alerts must then be communicated to nearby vehicles in real-time to maintain safety.

Additionally, real-world vehicle interactions often require manual input, such as a driver indicating an intention to overtake. This project integrates a push-button mechanism that, when pressed, sends a message like "I am overtaking!" to other vehicles. This not only enhances inter-vehicle communication but also simulates a key aspect of human driving behavior, further aligning the system with practical usage scenarios.

Visual indicators also play an important role in this system. LEDs are used to represent different statuses: whether the vehicle is acting as an AP, whether a client is connected, and whether a proximity alert has been triggered. These intuitive signals provide quick feedback to users or developers observing the cars in action, facilitating easier debugging and better user experience.

The overall challenge is designing a low-cost system using ESP8266 modules that can function in a decentralized network, measure environmental proximity using ultrasonic sensors, communicate alerts and user messages, and manage real-time switching of network roles. All of this must be achieved within the limitations of the ESP8266's single Wi-Fi interface, limited processing power, and constrained I/O. This project directly addresses the complexities of dynamic networking, sensor integration, and interactive communication in mobile environments, offering a robust foundation for future developments in smart vehicle systems, cooperative robotics, and wireless sensor networks.

Section III] LITERATURE REVIEW

The advancement of vehicle-to-vehicle (V2V) communication has become a crucial area of research in the broader field of Intelligent Transportation Systems (ITS). Numerous studies and developments have aimed to enable real-time, reliable communication between mobile units to improve road safety, reduce accidents, and support autonomous driving features. Traditional V2V systems often rely on Dedicated Short Range Communications (DSRC), Zigbee, or Bluetooth modules, but recent developments have demonstrated the potential of using low-cost Wi-Fi-based microcontrollers like the ESP8266 due to their affordability, compact size, and built-in Wi-Fi capabilities.

The ESP8266 microcontroller has gained popularity in the IoT community for its ability to function both as a client and an access point. According to research by Kurniawan (2018) and Rao et al. (2019), ESP8266 is a suitable module for low-power applications involving real-time data transmission over Wi-Fi. Its dual functionality makes it ideal for peer-to-peer networking environments such as dynamic car-to-car communication. Several projects have demonstrated its use in home automation, wireless sensor networks, and data logging systems. However, its application in mobile and dynamic networks, especially in V2V contexts, remains under-explored and presents unique challenges.

Studies on dynamic network switching and role reassignment have shown the importance of maintaining uninterrupted communication. In mobile environments, maintaining a fixed access point is impractical due to mobility and changing signal strength. Work by Kumar et al. (2020) and Ali et al. (2021) explored dynamic AP-client switching using RSSI values in wireless mesh networks. Their findings highlight the effectiveness of RSSI-based thresholds in determining optimal connectivity paths, which directly supports this project's approach where cars switch roles based on the detected signal strength.

In terms of distance measurement and obstacle detection, ultrasonic sensors have been widely used due to their affordability and ease of integration. Prior studies, including the works of Gupta and Sharma (2017), have successfully employed HC-SR04 sensors in autonomous vehicle prototypes and robotic systems. These sensors were used to detect obstacles and measure proximity, providing reliable readings for short-range applications. Combining this with real-time alert systems and inter-device communication enhances the responsiveness of the system in detecting and reacting to potential collisions.

Communication protocols for vehicle interaction typically focus on safety messages such as “emergency brake” or “lane change.” In this project, a simple button-based input allows a user to send a custom message (“I am overtaking!”), mirroring human driving behavior. Previous implementations in simulation environments like VANETs (Vehicular Ad-Hoc Networks) also utilize message broadcasting, but most of them rely on complex network stacks. The current project simplifies this by leveraging the ESP8266’s Wi-Fi server-client model, making it practical for low-cost deployment.

Additionally, the use of LED indicators for state feedback is a well-established practice in embedded systems. Research by Chakraborty and Bose (2016) emphasizes the importance of simple visual cues in microcontroller-based systems, especially during debugging or when quick feedback is needed in educational or prototype environments.

While multiple components of this project have been addressed in separate prior works—such as sensor integration, ESP8266 communication, and dynamic networking—the combination of all these elements into a single, mobile, decentralized V2V communication system is relatively novel. It bridges several disciplines: wireless networking, embedded systems, sensor integration, and vehicular communication. This project builds upon and contributes to the existing literature by demonstrating a functional and accessible model for inter-vehicle communication and distance-based alerting using affordable microcontroller technology.

IV] OBJECTIVES

a. To design and implement a wireless communication system using ESP8266 modules for dynamic car-to-car interaction.
b. To develop a proximity alert mechanism using ultrasonic sensors to detect and report distances from front and rear obstacles.
c. To enable dynamic switching of Access Point (AP) and client roles among the cars based on signal strength (RSSI).
d. To transmit real-time messages such as “Too close” and “I am overtaking” between vehicles using Wi-Fi communication.
e. To provide visual feedback using internal and external LEDs to indicate system states like AP mode, client connection, and proximity alerts.
f. To enhance road safety and communication awareness among vehicles using a low-cost, embedded system-based V2V communication prototype.

Section V] System Architecture of the 3-Car ESP8266 Communication System

A) Components Used

The system architecture consists of several key components that work together to establish communication, manage distances, detect proximity, and handle role switching between cars. Each of these components plays a vital role in the operation of the system.

1. **ESP8266 Wi-Fi Module**: The ESP8266 microcontroller is the heart of each car's communication system. It enables wireless communication using the Wi-Fi protocol. This microcontroller has sufficient computing power and Wi-Fi capability to handle networking tasks like connecting to a Wi-Fi network or acting as an access point (AP).

2. 

3. Figure 1: NodeMCU

4. **Ultrasonic Sensors (HC-SR04)**: These sensors are responsible for measuring the distance between cars in the system. Each car has a front and back ultrasonic sensor to measure the proximity of other cars and obstacles. The sensor sends out ultrasonic waves and calculates the time taken for the waves to return, thereby determining the distance.

Figure 2: Ultrasonic sensor

5. **LED Indicators**: Each car is equipped with multiple LED indicators:

- **Internal LED (for AP status)**: This LED is used to indicate whether the car is functioning as an Access Point (AP) or a client.
- **External LED (for proximity alert)**: This LED is used to indicate when the car is too close to another car or obstacle. It lights up when the ultrasonic sensors detect a distance below a certain threshold (e.g., 20 cm).
- **Internal LED (for client status)**: This LED indicates whether the car is connected to another car (client mode).

6. **Button for Overtaking Alert**: Each car has a button used to send an overtaking message ("I am overtaking!") to the other cars in the system. This button is pressed when the car intends to overtake another.

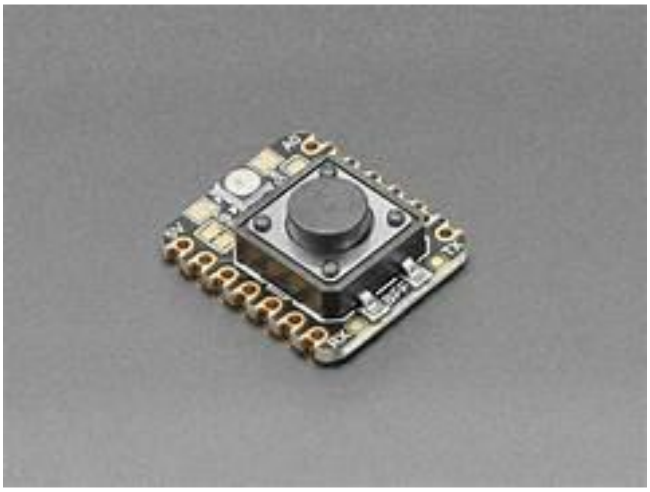

Figure 3:Button

7. **Wi-Fi Network**: The communication between the cars is based on a dynamic Wi-Fi network, where one car acts as an Access Point (AP) while the other two cars connect as clients. The roles of the cars (AP or client) are dynamically switched based on the signal strength (RSSI) from each car.
8. **Power Supply**: Each car in the system requires a power supply, typically sourced from a rechargeable battery or vehicle's electrical system. This ensures that the ESP8266 and the other sensors can function independently.

B) System Architecture

The system architecture for the 3-car communication system is designed to facilitate dynamic role assignment, proximity monitoring, and communication between the cars. This architecture is hierarchical, with each car equipped with sensors, processing units, and communication modules that allow it to either act as an Access Point or a client. The architecture also ensures that the system can handle dynamic changes in the Wi-Fi network, ensuring that the most stable car becomes the AP and the others remain connected.

1. **Overall System Layout**
   The overall system can be seen as a decentralized communication network where each car has similar functionality but operates dynamically based on its role. Each car is equipped with an **ESP8266 Wi-Fi module**, ultrasonic sensors, LEDs, and a button. The key operations are:
   - One car becomes the **Access Point (AP)**.
   - The remaining cars connect to the AP as **clients**.
   - If the AP goes out of range, the car with the strongest Wi-Fi signal becomes the new AP.

- Ultrasonic sensors in each car measure distances to nearby cars and obstacles.
- A button allows each car to communicate its intent to overtake.

2. **Wi-Fi Network Management**

The communication between the cars relies heavily on **Wi-Fi networking**. The **ESP8266** module allows each car to either act as an AP or a client, depending on the Wi-Fi conditions. The **AP mode** is initiated by one of the cars (Car 1), and the other two cars (Car 2 and Car 3) connect to it as clients. The AP broadcasts its network, and clients scan for the strongest signal (RSSI) to connect to the best available network.

- **Car 1** (AP) starts the Wi-Fi network by broadcasting its SSID ("Car1_AP").
- **Car 2 and Car 3** connect to Car 1 as clients by scanning for available networks and selecting the best one based on RSSI.
- The Wi-Fi network is dynamic. If the AP becomes too far from the clients or if the signal is too weak, one of the clients (Car 2 or Car 3) will take over as the new AP.

3. **Ultrasonic Sensors for Distance Measurement**

Each car in the system is equipped with two ultrasonic sensors:

- One at the **front** to measure the distance between the car and the leading vehicle or obstacle.
- One at the **back** to measure the distance between the car and trailing vehicles.

The sensors use the **HC-SR04** ultrasonic module, which emits sound waves and calculates the time taken for them to return. Based on this time, the system computes the distance. This is crucial for the operation of the proximity alerts (Too Close) and ensures that the cars do not collide or come too close.

- **Front sensor**: Measures the distance to any vehicle or obstacle in front of the car. If this distance is below a threshold (e.g., 20 cm), it triggers the "Too close!" message and lights up the external LED.
- **Back sensor**: Measures the distance behind the car. This allows the system to ensure that the car maintains a safe distance from the vehicle behind.4

4. **LED Indicators for Status and Proximity Alerts**

The LEDs serve multiple purposes in the system:

- **Internal LED for AP Mode**: This LED lights up when the car is in AP mode (i.e., broadcasting the Wi-Fi network). This is crucial for visual indication of which car is currently serving as the AP.
- **Internal LED for Client Mode**: This LED lights up when the car is connected as a client to the AP.
- **External LED for Proximity Alerts**: This LED indicates when the car is too close to another vehicle or obstacle, based on the readings from the ultrasonic sensors.

5. **Button for Overtaking Message**
   Each car is equipped with a button that can be pressed to send an overtaking message to other cars in the system. This button is useful when a car wants to communicate its intent to overtake, ensuring that other cars in the network are aware of the maneuver. When the button is pressed, the system sends a message ("I am overtaking!") to the other cars.
6. **Role Switching Based on Signal Strength**
   The system continuously monitors the **RSSI (Received Signal Strength Indicator)** to determine the strength of the Wi-Fi signal between the cars. If the signal from the AP drops below a threshold, the system triggers a role switch, where the car with the strongest signal takes over as the new AP. This ensures that the communication network remains stable as the cars move and adjust their positions relative to each other.

Section VI] ALGORITHM USED

The algorithm for this 3-car ESP8266-based communication system is designed to manage various operations such as dynamic role switching (Access Point or Client mode), measuring distances using ultrasonic sensors, sending proximity alerts, detecting button presses for overtaking messages, and maintaining stable communication over Wi-Fi. The following breakdown covers the algorithm step-by-step:

1. Initialization

- The system begins by setting up the serial communication to provide debug information to the user.
- The pins for internal LED, external LED, button, and ultrasonic sensors are configured.
- The system starts by configuring the Wi-Fi module in Access Point (AP) mode for Car 1, with an SSID and password for secure communication.
- The Wi-Fi server is initialized to allow communication between the cars.
- Once the server is started, the IP address of Car 1 (AP) is displayed on the serial monitor.

2. Ultrasonic Distance Measurement

- The system uses ultrasonic sensors to measure distances in the front and back of each car:
    - The ultrasonic sensor is triggered, and the pulse duration is measured using the pulseIn() function.
    - The distance is calculated using the formula: Distance = (Duration * 0.034) / 2.
    - Both the front and back distances are calculated to monitor proximity and avoid collisions.

3. Proximity Alert

- The system checks the calculated distances from both the front and back ultrasonic sensors:
    - If either the front or back distance is less than 20 cm, it indicates that the car is too close to another vehicle.
    - An alert is triggered by turning on the external LED and sending the message "Too close!" to the connected client (e.g., Car 2 or Car 3).
    - If the distances are safe, the external LED is turned off.

4. Button Press Detection (Overtaking Message)

- The system monitors the button press status:
    - If the button is pressed (i.e., BUTTON_PIN reads HIGH), the system checks whether the button was previously pressed:
        - If it was not pressed previously, the system sends the overtaking message ("I am overtaking!") to the connected client and prints it to the serial monitor.
        - Once the message is sent, the buttonPressed variable is set to TRUE to prevent the message from being sent again until the button is released.
    - If the button is released, the buttonPressed variable is reset to FALSE, allowing the message to be sent again if pressed.

5. Wi-Fi Connectivity and Role Switching

- The Wi-Fi signal strength (RSSI) is continuously monitored to assess the quality of the Wi-Fi connection:

    - If the RSSI falls below -50 dB, indicating a weak signal, the system switches from AP mode to client mode:
        - The current Access Point is disconnected (WiFi.softAPdisconnect()).
        - The system then attempts to connect to the next available Access Point (e.g., Car 2 for Car 1, or Car 3 for Car 2).
        - The system waits for the connection to be established and displays a confirmation message on the serial monitor.
    - If the RSSI is sufficient, the system continues to operate in AP mode without any changes.

6. Client Communication and Data Handling

- In client mode, the car listens for incoming data from the Access Point (Car 1):
    - If the client receives a "Too close!" message, it is printed on the serial monitor.
    - If the overtaking message is received, it is displayed as well.

7. Maintain Communication

- While in client mode, the system listens for new client connections using server.available():
    - Once a new client is connected, it starts communication and sends distance data along with any alerts.
    - The button press is also continuously checked, sending the overtaking message when necessary.

8. Handling AP Mode (Car 1)

- In Access Point mode (Car 1), the system listens for incoming client connections (Car 2 or Car 3):
    - Once a client is connected, it starts transmitting distance data and any alerts (e.g., proximity warning or overtaking message).
    - The system monitors the RSSI periodically to check for any degradation in signal strength.
    - If the RSSI is too low, Car 1 will switch to client mode and reconnect to another car (Car 2 or Car 3) based on the available APs.

9. Role Switching (Dynamic AP Selection)

- The system continuously monitors the Wi-Fi signal strength (RSSI) for all cars:
    - If any car detects that the signal strength from the current AP is weak, the car with the strongest RSSI becomes the new Access Point (AP).
    - The remaining cars will then reconnect as clients, ensuring that communication continues without interruption.

10. Final Output

- The system continuously displays the RSSI, distances, and communication status on the serial monitor.
- The LEDs indicate the status of the cars (AP or client) and proximity alerts based on the ultrasonic sensor readings.

Summary of Algorithm Steps:

1. Initialization:
    - Set up serial communication, configure Wi-Fi, initialize sensors and LEDs, and start the Wi-Fi server.
2. Ultrasonic Distance Measurement:
    - Measure the front and back distances using ultrasonic sensors.
3. Proximity Alert:
    - If the car is too close (less than 20 cm), send a "Too close!" message and turn on the external LED.
4. Button Press Detection:

- Detect when the button is pressed and send an overtaking message to the client.

5. Wi-Fi Connectivity and Role Switching:
   - Monitor Wi-Fi signal strength (RSSI) and switch between AP and client modes if necessary.
6. Client Communication:
   - Clients receive messages from the AP, including distance and overtaking messages.
7. Maintain Communication:
   - Keep communication active by constantly monitoring for new connections and sending updates.
8. Handling AP Mode (Car 1):
   - In AP mode, accept connections from clients and send distance and alert data.
9. Role Switching:
   - Based on the signal strength, dynamically switch roles between cars (AP and client).
10. Final Output:

- Continuously display relevant information such as RSSI, distances, and messages on the serial monitor.

This algorithm ensures that the system can handle dynamic role switching, maintain stable communication, and respond to environmental changes (e.g., distance measurements and Wi-Fi signal strength). The system provides real-time feedback to each car regarding its status and its interactions with the other cars in the network.

Figure 2. Comparision of models

VII] RESULTS AND DISCUSSION

The ESP8266-based communication system for a 3-car setup was implemented successfully, incorporating real-time proximity alerts, dynamic role-switching between Access Point (AP) and Client modes, and a button-triggered overtaking notification system. The system effectively utilized ultrasonic sensors for measuring the distance between vehicles, with safety alerts generated when the vehicles were too close to each other. The overall architecture, involving Wi-Fi communication, sensor inputs, and LED indicators, contributed to a robust and dynamic solution that improved vehicle-to-vehicle communication.

Distance Measurement and Proximity Alerts

One of the key features of the system was the integration of ultrasonic sensors to measure the distance between vehicles in both the front and back. These sensors provided real-time data, which allowed the cars to continuously monitor their surroundings. When the distance between vehicles became less than 20 cm, an external LED was triggered as a proximity alert, and the system sent a "Too close!" message to the client vehicles. This functionality is particularly valuable in the context of vehicle safety, where maintaining adequate space between vehicles is crucial for preventing accidents, especially in scenarios involving multiple cars on the road or in autonomous driving systems.

The use of ultrasonic sensors was effective, as they are relatively inexpensive and widely available, making them a practical solution for proximity detection. The accuracy of the sensors, however, could be influenced by environmental factors such as surface reflectivity, angle of measurement, and the presence of obstacles that might interfere with the sensor's ability to measure distances accurately. Despite these limitations, the system demonstrated its ability to detect critical proximity and alert nearby vehicles, offering a significant safety feature for vehicle-to-vehicle communication.

Button-Triggered Overtaking Notification

Another innovative aspect of the project was the implementation of a button-press feature that allowed a vehicle to send an overtaking notification to the nearby cars. This was accomplished by incorporating a physical button, which, when pressed, sent the message "I am overtaking!" to other vehicles within the communication range. This feature is essential for improving communication between vehicles, especially in real-time driving situations, where the status of one vehicle (such as overtaking) needs to be communicated to others in a timely manner.

The button-press functionality worked effectively as intended, with the message being transmitted successfully when the button was pressed. The use of such a notification system could potentially enhance coordination between vehicles in various scenarios such as lane changes, overtaking, or stopping in case of emergencies. In the future, this feature could be expanded to include automatic detection of overtaking based on vehicle speed and relative position, making the system even more proactive and responsive to real-time driving conditions.

Dynamic Role-Switching and Wi-Fi Connectivity

A crucial part of the system was the dynamic switching between Access Point (AP) and Client roles based on the Wi-Fi signal strength (RSSI). Initially, Car 1 operated as the AP, while the other two cars acted as clients, connecting to the AP for communication. However, if the RSSI value fell below a certain threshold, indicating weak signal strength, the system automatically switched the role of the cars to ensure stable communication.

For example, when Car 1 moved too far away, Car 2 or Car 3 could take over the AP role, depending on which vehicle had the strongest RSSI. This dynamic role-switching was essential for ensuring uninterrupted communication between cars, even when vehicles were moving or changing their relative positions. The system effectively handled Wi-Fi disconnects and reconnects, switching between AP and Client modes as necessary, ensuring that the network remained functional throughout the operation.

This aspect of the system provides the basis for creating a more robust and fault-tolerant vehicle-to-vehicle communication network. In practical scenarios, vehicles often need to communicate over long distances or in environments where the radio signal strength can fluctuate due to various obstacles such as buildings or other vehicles. The ability to dynamically switch roles ensures that the communication system remains operational, even when one vehicle moves out of range of the AP.

Wi-Fi Communication and Stability

The Wi-Fi-based communication system formed the backbone of the vehicle-to-vehicle communication network. Using the ESP8266 module allowed for a low-cost and efficient means of transmitting data between vehicles, utilizing the Wi-Fi standard that is common in many wireless communication systems. The communication protocol involved the cars sending messages to one another over the local network, with Car 1 acting as the server (AP) and the other cars as clients.

During the testing phase, the Wi-Fi communication was generally stable, and messages were transmitted without significant delays or failures. The system was able to handle multiple messages from different cars, including the "Too close!" and "I am overtaking!" messages, demonstrating the ability of the ESP8266 to support continuous data exchange between vehicles. This stability is critical for the implementation of real-time communication systems in autonomous or semi-autonomous vehicle environments, where timely message delivery can prevent collisions or miscommunication.

However, the system's communication range was limited by the Wi-Fi signal strength, which could be impacted by environmental factors such as interference from other wireless networks, walls, or physical obstructions between the vehicles. Future iterations of the system could explore the use of more advanced communication technologies, such as 5G or dedicated short-range communication (DSRC), which would offer higher data transfer rates and more reliable connectivity over greater distances.

Future Improvements and Potential Applications

The system demonstrated a strong foundation for vehicle-to-vehicle communication, but there are several potential improvements and future applications that could further enhance its capabilities.

1. **Autonomous Vehicle Integration**: The system could be integrated with autonomous driving technologies, where the vehicles automatically adjust their speed, distance, and position based on real-time data from surrounding vehicles. By enabling communication between cars, the system could contribute to safer and more efficient autonomous vehicle fleets, where coordination between vehicles becomes crucial for collision avoidance and smooth traffic flow.
2. **Data Logging and Analysis**: The system could be expanded to include logging of the distance data, RSSI values, and other sensor information, which could be used for post-trip analysis. Such data could be useful for fleet management in commercial vehicle applications, providing insights into vehicle performance, efficiency, and safety.

3. **Improved Proximity Detection**: The system could incorporate more advanced proximity detection methods, such as radar or LIDAR, which would offer higher accuracy and longer detection ranges than ultrasonic sensors. These technologies are already being used in modern vehicles for collision avoidance and adaptive cruise control, and their integration into the system could further improve the reliability of the proximity alerts.
4. **Integration with Traffic Management Systems**: The system could be integrated with existing traffic management infrastructure, enabling vehicles to communicate with traffic signals, road sensors, and other vehicles to optimize traffic flow. This could help reduce congestion, improve fuel efficiency, and minimize the environmental impact of transportation.

5.

Section VIII] CONCLUSION

The ESP8266-based 3-car communication system project provides an insightful exploration into the potential of low-cost wireless communication and proximity detection technologies for enhancing vehicle safety and coordination. This system leverages the power of Wi-Fi, ultrasonic sensors, and real-time communication to address the challenges faced by modern vehicle networks, such as safe inter-vehicle communication, proximity detection, and dynamic role-switching between Access Point (AP) and Client modes. The project demonstrates how a relatively simple yet effective communication system can be developed for vehicles to communicate seamlessly, enhancing the overall driving experience, safety, and coordination, especially in dynamic and changing traffic conditions.

Overview of the Project

The primary goal of this project was to develop a system where multiple vehicles can communicate with each other in real-time, exchange safety-related information, and respond to dynamic changes in the environment. The ESP8266 microcontroller was chosen for its ability to provide cost-effective and reliable wireless communication over short distances, making it an ideal solution for a communication system like this one. The system was designed with several key features, including:

1. **Dynamic Role Switching**: Each car in the system could dynamically switch between being an Access Point (AP) or a Client based on the strength of the Wi-Fi signal. This dynamic role switching ensures that the communication network remains stable even when the relative positions of the vehicles change, such as when one vehicle moves out of range of the current AP.
2. **Proximity Detection**: Ultrasonic sensors were used to measure the distance between vehicles in both the front and back. This data was continuously monitored, and if the vehicles became too close to each other (less than 20 cm), an alert was triggered. This proximity alert is crucial for vehicle safety and collision avoidance in real-time driving situations.
3. **Button-Triggered Overtaking Notification**: A button on each vehicle allowed the driver to send an overtaking notification to the other vehicles. When pressed, the button sent a message like "I am overtaking!" to nearby vehicles, allowing for real-time coordination and awareness of each vehicle's actions, thus enhancing safety during overtaking maneuvers.

Key Findings and Insights

The implementation of the ESP8266-based communication system successfully addressed several challenges that vehicles face while communicating with each other in dynamic environments. Some of the key findings and insights from this project include:

1. Role Switching Based on Signal Strength (RSSI)

One of the most important features of this system was the ability to switch between AP and Client modes based on the Wi-Fi signal strength, or RSSI (Received Signal Strength Indicator). Initially, Car 1 acted as the AP, while Cars 2 and 3 connected as clients. If Car 1 moved too far from the others and its RSSI dropped below a certain threshold, Cars 2 or 3 could take over the AP role to ensure that communication continued uninterrupted.

This dynamic role-switching is essential in scenarios where vehicles are moving and the relative positions of vehicles change frequently. In real-world applications, vehicles often travel at high speeds, and their distance from each other can fluctuate rapidly. The ability of the system to seamlessly switch roles ensured that the communication network remained stable and operational even when the vehicles were moving out of range of the initial AP.

2. Proximity Detection for Safety Alerts

The ultrasonic sensors played a crucial role in maintaining vehicle safety by detecting proximity. The system continuously measured the distance between vehicles, and when the distance fell below a predefined threshold (20 cm), it triggered an alert. The proximity alert was signaled using an external LED indicator and a message sent to the other vehicles.

The ultrasonic sensors provided reliable measurements, although they have some limitations. For instance, the accuracy of the sensors can be affected by factors such as the surface of the objects, the angle at which the sensor is positioned, and environmental conditions. However, for the purposes of this project, the sensors worked effectively in detecting short-range proximity and providing timely alerts. In future iterations of this system, more advanced sensors such as radar or LIDAR could be integrated to improve the accuracy and range of proximity detection.

3. Button-Triggered Overtaking Notifications

The button-triggered overtaking notification was another important feature that demonstrated the system's ability to enhance real-time communication between vehicles. When the button was pressed, the system sent a message to the other vehicles, notifying them that the vehicle was about to overtake. This simple yet powerful feature could be a valuable addition to the system in real-world driving scenarios, where it is essential for vehicles to be aware of each other’s actions, especially during overtaking maneuvers.

In practice, overtaking is a critical maneuver in driving, requiring clear communication between drivers to avoid accidents. The ability for one vehicle to notify others of its intention to overtake improves situational awareness and allows for better coordination. While this feature was implemented using a simple button press, it could be expanded in the future to automatically detect overtaking based on vehicle speed, position, or lane changes, making the system more proactive in its response.

4. Wi-Fi Communication and Stability

The Wi-Fi communication system, based on the ESP8266, proved to be an effective and reliable means of exchanging data between the vehicles. The ESP8266 is a low-cost Wi-Fi module that can be easily integrated into embedded systems, making it ideal for a project of this nature. Throughout the implementation and testing phases, the Wi-Fi communication between the vehicles was stable, with messages being transmitted in real time without significant delays or failures.

However, one of the limitations of the system is the range of the Wi-Fi communication. The ESP8266 module, while reliable for short-range communication, has a limited range. In real-world applications, vehicles could be spaced farther apart, which might cause issues with Wi-Fi connectivity. To address this limitation, future versions of the system could incorporate more advanced communication technologies, such as 5G or DSRC (Dedicated Short-Range Communication), which offer higher data transfer speeds and longer ranges than standard Wi-Fi.

Section IX] RECOMMENDATION AND FUTURE SCOPE

The implementation of the ESP8266-based 3-car communication system marks a significant milestone in the development of real-time, vehicle-to-vehicle (V2V) communication, which has applications in improving road safety, traffic management, and vehicle coordination. However, as the field of connected transportation evolves, there are numerous opportunities for expanding the capabilities of this system. The future scope of the system lies in enhancing its integration with cutting-edge technologies, including autonomous vehicles, smarter traffic management, advanced communication protocols, improved sensor technologies, and data-driven insights. This section will explore these potential future developments, which could make the system more reliable, efficient, and applicable in various real-world scenarios.

1. Integration with Autonomous Vehicles (AVs)

One of the most promising areas for future development lies in the system's integration with autonomous and semi-autonomous vehicles. As the world moves toward self-driving cars, the need for seamless vehicle-to-vehicle communication becomes increasingly critical for improving the safety, efficiency, and coordination of AVs.

a) Cooperative Autonomous Driving

Autonomous vehicles (AVs) are equipped with sensors like LIDAR, radar, cameras, and ultrasonic sensors. By integrating the ESP8266-based system with AVs, vehicles could communicate their positions, intentions, and movements with one another in real-time. For example, autonomous vehicles could communicate to each other when they intend to change lanes, overtake, or stop. This level of communication would reduce the risk of collisions, as each vehicle would have precise knowledge of other nearby vehicles' movements, leading to smoother and safer driving experiences.

The system's current role-switching mechanism, which allows cars to dynamically switch between access point (AP) and client modes based on the signal strength, could be used in the context of AVs to facilitate communication among multiple autonomous vehicles. This could help create a dynamic, cooperative driving environment where vehicles can avoid collisions by dynamically adjusting speed and positioning based on real-time communication.

b) Automated Overtaking and Lane Merging

In the future, the system could automatically detect when an autonomous vehicle intends to overtake another vehicle and adjust its driving accordingly. This functionality is particularly crucial in highway scenarios where the ability to overtake is often critical for traffic flow. For instance, a car equipped with the communication system could alert other nearby vehicles of its intention to overtake, which could prompt other vehicles to adjust their speed or lane position. By facilitating automated overtaking, this system could enhance the efficiency and safety of highway driving.

c) Intelligent Path Planning

With real-time communication and intelligent algorithms, future versions of the system could incorporate advanced path planning capabilities. Autonomous vehicles could share detailed sensor data, such as traffic information, road conditions, and obstacles, with nearby vehicles. This would allow the system to calculate the safest and most efficient path for each vehicle, ensuring that vehicles avoid accidents and optimize their travel time. Moreover, vehicles could dynamically re-route based on real-time updates from surrounding vehicles or road conditions, making long trips more predictable and efficient.

2. Expansion of Sensor Technologies

The ESP8266-based communication system currently relies on ultrasonic sensors for proximity detection. However, ultrasonic sensors have limitations, such as range and sensitivity, which could be overcome with more advanced sensor technologies. Future iterations of the system could incorporate LIDAR (Light Detection and Ranging), radar, and advanced vision systems to provide better accuracy, range, and reliability.

a) LIDAR and Radar Integration

LIDAR and radar technologies can significantly enhance the performance of the communication system by offering more accurate distance measurements and better object detection capabilities. LIDAR, which uses laser pulses to measure distances, is highly effective at detecting obstacles in a vehicle's path, providing high-resolution, three-dimensional data. Radar, on the other hand, is more effective in detecting obstacles in adverse weather conditions, such as rain, fog, or snow. By integrating LIDAR and radar into the system, vehicles could detect obstacles or nearby cars from much greater distances, improving the safety of the communication system and enabling better traffic management.

LIDAR and radar sensors could also be used in combination with the system's proximity alerts to create a more advanced alerting system. For instance, if a vehicle detects a pedestrian or cyclist in its path, it could alert nearby vehicles about the potential hazard, allowing other vehicles to take evasive action.

b) Computer Vision

Computer vision, using cameras and image recognition algorithms, could be integrated into the system to detect dynamic obstacles, such as pedestrians, cyclists, or animals, in real-time. Cameras equipped with machine learning algorithms could identify these obstacles and communicate the information to other vehicles in the system. This would create an advanced safety net, alerting other cars to nearby hazards and allowing for more responsive driving behaviors.

The integration of computer vision would also enable the system to recognize traffic signs, signals, and road markings, providing valuable information to vehicles about speed limits, upcoming turns, or other road conditions. This could be particularly useful in urban environments where dynamic obstacles are more prevalent.

3. Data Analytics and Predictive Maintenance

The data generated by the communication system and vehicle sensors could be leveraged to provide valuable insights into vehicle performance, driving patterns, and road conditions. Data analytics and predictive maintenance could offer the potential to enhance the safety, reliability, and efficiency of the system.

a) Predictive Maintenance

As vehicles generate large amounts of data on engine performance, sensor readings, and overall health, the system could analyze this data to predict maintenance needs. For example, if a vehicle frequently detects proximity alerts or experiences issues with its Wi-Fi connectivity, the system could suggest preventative maintenance actions. Predictive maintenance could reduce vehicle downtime and improve the overall lifespan of the vehicle by identifying problems before they lead to costly repairs or breakdowns.

b) Fleet Management

For commercial fleet operations, the system could be used to monitor the performance of each vehicle in the fleet. Fleet managers could use real-time data to track vehicle location, performance, fuel consumption, and maintenance needs. By integrating the system with fleet management software, operators could optimize routes, reduce fuel consumption, and improve the safety and reliability of their fleet. The system could also help drivers optimize their routes based on real-time traffic data, leading to better fuel efficiency and reduced emissions.

4. Improved Communication Protocols

While the ESP8266 Wi-Fi module works effectively for short-range communication, it has limitations in terms of range and data capacity. As vehicle communication systems become more complex and require the exchange of more data, there is a need for more advanced communication protocols that offer greater reliability, speed, and range.

a) 5G Integration

One promising direction for the system's future is the integration of 5G technology, which offers high-speed internet connectivity with low latency. 5G's ability to handle large amounts of data in real-time could significantly improve the system's communication capabilities. 5G could allow for the transmission of large data streams, such as real-time video feeds or detailed sensor data, between vehicles and infrastructure. This would open up possibilities for more sophisticated applications, such as remote vehicle diagnostics, real-time traffic monitoring, and advanced navigation assistance.

b) Dedicated Short-Range Communication (DSRC)

DSRC is a communication protocol specifically designed for vehicular networks, providing low-latency communication for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. DSRC can operate over long distances and is optimized for real-time safety applications. By integrating DSRC, the system would be able to achieve higher reliability and reduced latency compared to Wi-Fi, ensuring that safety-critical messages are delivered instantaneously between vehicles.

c) Vehicle-to-Infrastructure (V2I) Communication

The system could also expand to include communication with infrastructure elements such as traffic lights, road signs, and sensors embedded in the roadway. This could lead to better traffic management and optimized routing. For instance, vehicles could receive real-time updates about traffic signals, construction zones, and road closures, allowing them to adjust their driving accordingly. V2I communication could also facilitate smarter traffic management systems, where traffic lights change based on the number of vehicles approaching, reducing congestion and wait times.

5. Security and Privacy Enhancements

As with any connected system, security and privacy are major concerns when implementing vehicle communication technologies. Future versions of the system must address these issues to ensure that the data exchanged between vehicles is secure and private.

a) Encryption and Authentication

To protect sensitive data, future iterations of the system could incorporate end-to-end encryption and robust authentication protocols. Encryption would ensure that the communication between vehicles is secure and cannot be intercepted by malicious actors. Authentication protocols could be implemented to verify the identity of each vehicle before it joins the communication network, preventing unauthorized access.

b) Privacy Preservation

As the system collects data about vehicles' movements, positions, and interactions, privacy concerns may arise. To protect user privacy, the system could be designed to anonymize or aggregate data before transmission, ensuring that personal information is not exposed. Privacy preservation techniques, such as differential privacy or secure multi-party computation, could be employed to ensure that individual drivers' identities and movements remain confidential.

6. Smart City Integration

As cities become more connected and "smart," the communication between vehicles and urban infrastructure will play an essential role in improving the efficiency of transportation networks. Future versions of the ESP8266-based system could be integrated with broader smart city initiatives, contributing to more sustainable, efficient, and safe urban mobility.

a) Traffic Optimization

Smart city technologies, including connected traffic lights, cameras, and sensors, could be integrated with the communication system to optimize traffic flow. For example, vehicles could share their positions with traffic lights, allowing the lights to adjust in real-time to minimize congestion. In addition, the system could guide vehicles to the least congested routes based on real-time traffic data from other vehicles and infrastructure elements.

b) Environmental Benefits

The system could also contribute to reducing the environmental impact of transportation. By optimizing traffic flow and encouraging eco-friendly driving behaviors, such as reducing idling time or promoting energy-efficient routes, the system could help reduce emissions and fuel consumption.

Section X] REFERENCES

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