Implementation of a WiFi-based V2V-V2I Communication Unit for Low Speed Vehicles

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***Abstract*—Vehicle to Vehicle (V2V) and Vehicles to Infrastructure (V2I) are key communication technologies for intelligent transportation system (ITS) to exchange the transparent information such as GPS positions, velocities, traffic status and environment conditions between vehicles as well as between vehicles and infrastructure on the road. These technologies support preventing accidents by releasing a warning as well as reducing traffic congestion. In this paper, design and implementation of a small-size WiFi-based prototype of a V2V-V2I communication unit for low speed vehicles is presented. WiFi, a popular wireless communication technique, was chosen since it is not only a cost-effective choice, but it is also suited for low-speed vehicles like motorbikes, bikes, tracking UAVs, and ground robots. This work analyzes and implements essential use cases and related algorithms to demonstrate the efficiency of V2V and V2I communication using WiFi technology. The results demonstrate the proposed unit's technological feasibility in real-world vehicles.**

***Index Terms*—V2V, V2I, ITS, ESP WiFi, Smart city**

I. Introduction

Under the pressure of rising populations and urbanization, many cities in the world used advanced technologies of the Industrial Revolution 4.0 to help them manage their resources in an efficient manner and become ”smart cities”. There are many areas which a smart city covered such as transportation, health, electric, lightening, waste, and so on. But in developing countries such as Vietnam, smart transportation is the most important area of smart city. Since various types of vehicles gain extensive popularity, traffic accident involving cars, bikes, and vulnerable pedestrians has been one of the most serious problems in the transportation system nowadays. In Vietnam, around 40,000 peoples die and 80,000 peoples are injured in last 4 years in traffic accidents [1]. Besides, traffic congestion is causing quite serious consequences for people, so urgent measures are being taken almost immediately to prevent and reduce congestion in cities in Vietnam. To enhance the transport safety reduce accidents and traffic congestion, researchers and industries are focusing on vehicular networking to sense everything (V2X).

Vehicle-to-vehicle (V2V) communications comprises a wireless network where automobiles send messages to each other with information about their status including speed, location, direction of travel, braking, and loss of stability. V2V technology usually uses dedicated short-range communications (DSRC), a standard set forth by bodies like FCC and ISO. V2V is a mesh network, meaning every node (car, smart traffic signal, etc.) could send, capture and re-transmit signals.

Vehicle-to-infrastructure (V2I) technology is a communication framework that enables several vehicles to share information with a variety of devices supporting on the road, which usually call Road Side Units (RSU) [2]. Enabled by a network of hardware, software, and firmware, the V2I technology is typically wireless and bi-directional: information from infrastructure devices is easily transmitted to the vehicle through an ad-hoc network and vice versa. V2I sensors are used in intelligent transportation system (ITS) to capture data and issue road users with real-time advisories about various incidents on the road: traffic congestion, construction sites, road conditions, parking zones and so on.

The interaction between the various involved entities in V2V and V2I technologies requires the information exchange to use proper communication protocols, such as the IEEE 802.11p [3] and LTE-V2V [4]. Other protocols that can be used in vehicular communications are Bluetooth [5] and IEEE 802.15.4/ZigBee [6], or WiFi [7].

Since almost V2V and V2I are applying for automobiles by using a Dedicated Short Range Communication (DSRC) module, which is usually high cost. As you can see in the Fig. 1, there are, however, multiple types of communications between vehicles and infrastructure in a real environment. Infrastructure communication units or Road Side Units (RSU) are placed at fixed points such as the traffic lights. When a vehicles' collision or traffic congestion occurred or potentially to be occurred, the information will be transmitted between vehicles and infrastructures and even the Internet. Therefore, the smart city management can give appropriate actions. In some cases, UAVs can be used as a Flying RSU to extend the mesh network. To make this kind of V2V-V2I mesh ad-hoc network, many communication units has been created in the ITS systems, which requires a high investment. Vehicles such as motorcycles, bikes, UAVs usually moving at a lower speed than automotive. It is also difficult for them to be equipped with an expensive DSRC module. In this paper, a WiFi-based V2V-V2I communication unit is developed for low speed vehicle.

The rest of the paper is organized as follows, section II provides design and implementation of the WiFi-based V2V-V2I communication unit and its operation in practical use cases. Section III deals with the results and discussion and finally section IV gives the conclusion about the work.

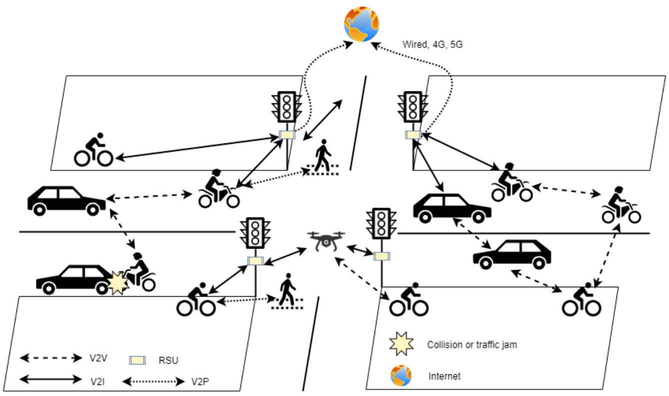

Fig. 1: Overview of the V2I-V2V communication in a smart city.

II. Design V2V-V2I Communication Unit

A. Hardware Integration

The designed communication unit consists of three sensors, a compact MCU-WiFi-Camera (ESP32-CAM) module and an LCD display as shown in Fig. 2 below.

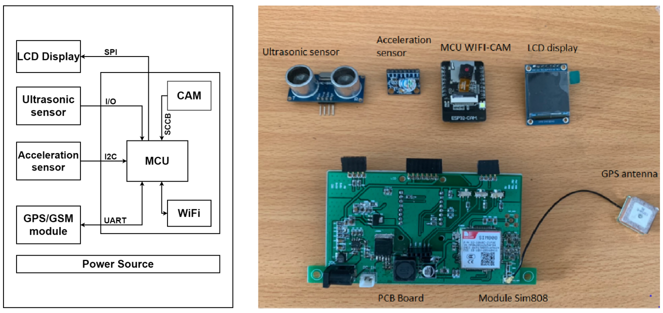

Fig. 2: Block diagram of the V2V-V2I communication unit based on WiFi

The ESP32-CAM is a full-featured micro-controller that also has an integrated video camera and microSD card socket. This low-cost integrated module is very suitable for IoT devices requiring a camera with advanced functions like image tracking and recognition. A 1.3 inch TFT LCD screen ST7789 is used to show the extract information from sensors and the received messages from other vehicles. The display has 240 x 240 pixels resolution and allows to display of a high-quality image. SIM808 module is integrated with a high-performance GSM/GPRS engine, a GPS engine, and a BT engine. SIM808 is a quad-band GSM/GPRS module that works on frequencies GSM 850MHz, EGSM 900MHz, DCS 1800MHz, and PCS 1900MHz. The GPS solution offers best-in-class acquisition and tracking sensitivity, Time-To-First-Fix (TTFF), and accuracy. The compact SIM808 provides both GPS information as well as another communication option through 3G/4G. For collision detection, ultrasonic ranging module HC-SR04 will be used. It provides a 2cm - 400cm non-contact measurement function with a ranging accuracy that can reach 3mm. The MPU6050 sensor is a Micro-Electro-Mechanical System (MEMS) which consists of a 3-axis Accelerometer and 3-axis Gyroscope inside it. MPU6050 measures acceleration, velocity, orientation, displacement, and many other motion-related parameters of a system or object.

B. WiFi-based protocol for V2V-V2I communication

ESP-WIFI-MESH (Fig. 3a) is a wireless communication network with nodes organized in a mesh topology using the simultaneous AP-STA feature on Espressif SoCs. It provides a self-forming and self-healing network, with ease of deployment. The network topology of ESP-WIFI-MESH can scale up to 1000 nodes in large areas, without requiring any specific WiFi infrastructure support.

ESP-NOW (Fig. 3b) is yet another protocol developed by Espressif, which enables multiple devices to communicate with one another without using WiFi. The protocol is similar to the low-power 2.4GHz wireless connectivity that is often deployed in wireless mouses. So, the pairing between devices is needed prior to their communication. After the pairing is done, the connection is secure and peer-to-peer, with no handshake being required. ESP-NOW protocol provides a fast, connection-less WiFi communication involving short packet transmission. There is a vendor-specific action frame in which the message is embodied and gets transmitted from one device to another device, the transmission is connection-less.For the information exchange between devices and to deliver a broadcast message, adding a peer with the broadcast address is done. Local device and peer device details are preserved in the low-level layer of ESP-NOW. Sending and receiving call back functions informs us about the success/failure of packet transmissions in broadcast/multicast communication. [8]

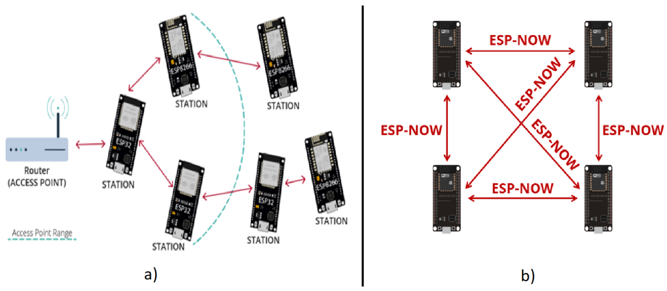

Fig. 3: a) ESP-MESH protocol [9] b) ESP-NOW protocol [10]

C. Use Cases for V2V-V2I Communication based on ESP WiFi protocol

Important use cases of WiFi-based V2V-V2I communications are evaluated in this section. We divided the complicated communication cases in Fig. 1 into 04 general uses cases as shown in Fig. 4.

a) Use case 1: V2V Communication via ESP-NOW protocol: If a vehicle cannot detect any activated activated RSU, the unit is set to use ESP-NOW protocol and be ready to make a direct communication connection between vehicles as shown in Fig. 4a.

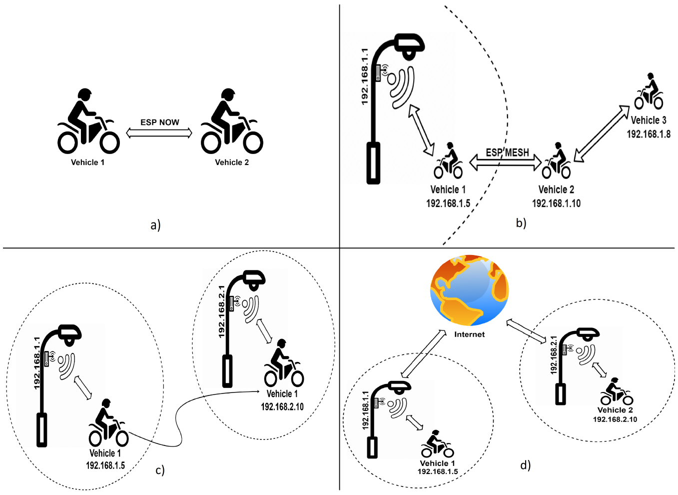

Fig. 4: a) Direct V2V communication via ESP NOW b) V2V-V2I Communication via ESP Mesh c) V2I communication when a vehicle travel from one RSU to another one d) V2V-V2I communication between vehicles at different RSU locations

b) Use case 2: V2V-V2I Communication via ESP-MESH protocol: In this case (Fig. 4b), when a vehicle (for example, vehicle 1) is moving inside the coverage of an RSU. It is connected to that RSU and set for ESP-MESH protocol and be ready to become a mesh point to extend the RSU network. Therefore, other vehicles (for example, vehicle 2) are outside the coverage range of the RSU can connect to the RSU network through a mesh connection with vehicle 1. Then vehicle 2 can transfer data to RSU via vehicle 1. So both V2V and V2I communication are established. Vehicle 2 then can become another mesh point of the RSU network to extend it much further (for example, vehicle 3).

c) Use case 3: V2I Communication when a vehicle travel from one RSU to another one: A vehicle will automatically connect to a RSU when it is moving inside its coverage region. This use case show the switching ability of a vehicle when it is moving from a RSU (for example, RSU1) to another RSU (for example, RSU2) as shown in Fig. 4c.

d) Use case 4: V2V communication between 2 vehicles far away each other based on V2I communication and the Internet: In this case (Fig. 4d), RSUs are connected through the Internet, vehicles at different locations of the city still can receive and transfer the information to each other through RSUs and the Internet.

D. Collision detection and Communication algorithms

1) Collision Detection Algorithms: A real traffic collision is detected if the following conditions are occurred simultaneously:

- Distance from vehicle to front obstacles measured by ultrasonic sensors is less than 20 cm in more than 15 seconds.
- GPS signal does not change value for a period of time.
- Value of acceleration sensor is suddenly changed to 0 m/s.

When a car have an accident it will send the information about its location (latitude and longitude), distance to the obstacles and warning message to other cars.

2) V2V-V2I Communication Algorithms: Fig. 5 shows the V2V-V2I communication algorithm in a vehicle. First, information from all sensors and GPS/GSM module are periodically check for updating vehicle status and collision detection. Then, the communication procedure begins. If the vehicle cannot detect any RSUs (Use case 1, Fig. 4a), the ESP-Now protocol is employed. Broadcast messages are delivered in real-time so that all recent vehicles may receive the messages. The vehicle examines the message to see if the broadcaster is in its Mac address list; if it is not in the list, the MAC address of the broadcaster will be added. When a collision occurs, the vehicles will determine which MAC address caused the collision and display that collision information on the screen. If the vehicle detects more than one RSUs, ESP-Mesh is employed. The vehicle will connect to the RSU and prepare to connect to other vehicles. Direct connections to the RSU (Fig. 4c) or indirect connections through methods in the router region are both possible (Fig. 4b,4d).

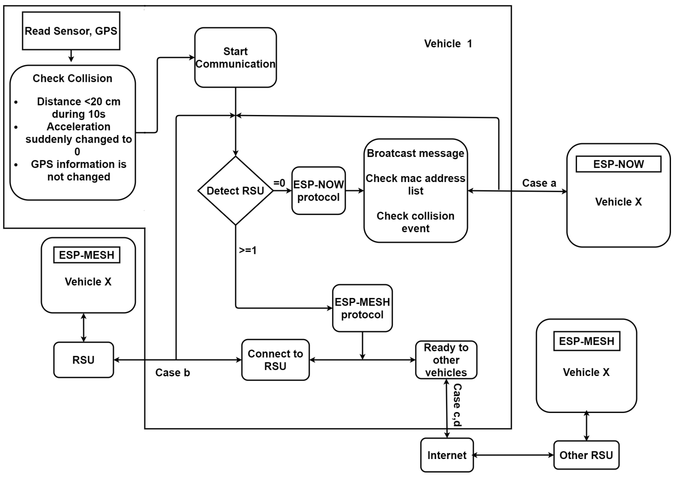

Fig. 5: V2I-V2V Communications Algorithm of a vehicle

III. Results and Discussions

We set up many experiments for all the use cases, one of them is shown in Fig. 6a. Our device will be mounted on the top of 2 motorbikes. After testing all 04 cases, our device was successful in transmitting and receiving collision data from the side of the accident vehicle. Our experimental results have been successfully displayed on the LCD display screens of vehicles as shown in Fig. 6b. Our devices are also capable of transferring images from the camera built into the ESP32 CAM to the RSUs as shown in Fig. 6c.

The outcomes of the experimental approach are shown in the Table 1. Because V2V communication in Use Case 1 is unrelated to RSU, we separate it into two smaller examples to compute the distance between two vehicles traveling in opposite directions and the same direction. The maximum speed in both situations is 30 km/h, the maximum distance

Fig. 6: a) Overview of a real-time experiments b)A full message of V2V or V2I communication c) Image transferred from vehicle through RSUs and the Internet

TABLE I: Results of real-time experiments test

Cases	Max. Speed	Dist. to RSU	Vehicles' Dist.	Image Transfer
Use case 1	30km/h	-	150m	No
Use case 2,4	25km/h	65m	40m	Yes
Use case 3	15km/h	30m	-	Yes

between two cars traveling in opposite directions is 150 meters, and for the same direction, the maximum distance is 120 meters, but it remains connected for a longer time than the previous scenario. On the other hand,for Use case 2 and 4, the vehicle's top speed is 25 km/h, the distance between vehicles outside the RSU's range and RSU is 65 meters, and the gap between vehicles near to the RSU's coverage borderline and the outside is 40 meters. For Use Case 3, the vehicle's top speed is 15 km/h since the vehicle moving at the distance to the RSU is 30 meters (boundary of the coverage region), the vehicle automatically connect to the RSU2 when it leave out of RSU1's coverage region and come into the RSU2's one.

IV. Conclusion

The design and implementation of a low-cost WiFi-based V2V-V2I communication unit have been presented. Hardware integration is optimized for size and cost. ESP-MESH and ESP-NOW are used as communication protocols. Essential use cases to show the technical feasibility of the proposed unit for both V2V and V2I communication for low-speed vehicles are analyzed and evaluated in real-time operation. The results show that the communication is successful at the vehicle's speed up to 30km/h for V2V and 25km/h for V2I. The maximum distance is up to 150m for V2V and 65m for V2I. The results prove the technical feasibility to apply the proposed unit to real vehicles. For future works, we will integrate the module into a large number of vehicles to evaluate the operation of a full-mesh V2V-V2I network.

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