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Design of Roadsite Unit (RSU) Based On ESP32 for Vehicle to Infrastructure (V2I) Communication System

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ABSTRACT
Number of vehicle users are increasing in Polmed now. The increasing is very huge if we compare limited campus land. As result of these conditions, disturbing convenience and productivity. Solution to overcome of this condition is implementing of communication system on vehicle user to reach information about outdoor condition. This system is known as Vehicle to Infrastructure (V2I) communication system. The infrastructure is here as roads and parking lots. V2I devices consists of OBU (Onboard Unit), RSU (Roadside Unit) and communication among them. There are some disturbances on the outdoor wireless network such as propagation, interferences, and coverage area. That's why in this study, how to design RSU device as Transceiver. RSU is made by Microcontroller ESP32. The stages of designing is consist of 3 stages, namely hardware and communication design, localhost-based information design and data measurement and monitoring. According to measurement, height positions of RSU is 3 m, the longest distance RSU toward OBU is 90 m, obtained power is -91 dBm. This value is still in device sensitivity of Microcontroller ESP32.

1. Introduction

Increasing the number of 4-wheel and 2-wheel vehicle users at Politeknik Negeri Medan (Polmed) is increasing. The current condition is 213 cars users and 3315 motorcycle users. Of course, the number of these vehicles is very large for limited campus area approximately 8.7 Ha. As a result, campus conditions are crowded with vehicles and can interfere with comfort and productivity. There is a need for a communication system for vehicle users, especially 4-wheel vehicles to easily get information about road conditions, parking lots and so on.

The communication system is commonly used on vehicles to monitor road conditions, parking lots and so on is the Vehicle to Infrastructure (V2I) communication system. Three important components in V2I communication are the Onboard Unit (OBU) mounted on the vehicle, the Roadside Unit (RSU) on the road infrastructure and the available transmission channel [1]. Transmission channels in the form of wireless networks are Digital Broadcasting, Cellular Systems and Dedicated Short-Range Communication (DSRC) [2].

In the V2I communication system, the vehicle can be connected with RSU devices installed on the roadside. RSU shares information to all vehicles connected to it and gets information from vehicles dynamically and in real-time [3]. V2I communication can also be client-server, RSU as a client that reads data from the sensor and sends it, then the server stores and processes the data [4].

There are many obstacles in wireless networks with outdoor conditions in the form of signal propagation, interference and signal coverage areas [5]. So this research is focused on designing a robust and dynamic RSU device so that it can perform a V2I communication system with good performance and subsequently the RSU device will be used for smart parking applications [6] [7] [8].

2. Theory

2.1. Intelligent Transport System (ITS)

Intelligent Transportation System (ITS) is an intelligent system for transportation that can provide efficiency, comfort and safety for the driver. The type of communication has found and they are communication between vehicles (Vehicle to Vehicle / V2V), communication between vehicles to infrastructure (Vehicle to Infrastructure / V2I) and communication between vehicles to all types of objects (Vehicle to Everything / V2X).

In general, ITS technology has been used in various countries. This technology is implemented in various fields, namely:

a. **Advanced Navigation System**
This system aims to guide the vehicle in order to get the shortest and optimal road route. Generally shaped digital maps based on Geographic Information System (GIS).

b. **Advance Traffic Management System**
This system provides real-time information about traffic conditions. Traffic jams, accidents and obstacles.

c. **Incident Management System**
This system is used to detect emergency events such as accidents, landslides / other disasters. The sensors will provide information to related parties for disaster mitigation.

d. **Electronic Toll Collection**
This system aims to save time on toll road users' payments so that there are no long queues at toll road exits / entrances.

e. **Advance for Safety Driving**
The vehicle is equipped with a number of sensors that help the driver to be safe. This sensor reads the distance between vehicles and gives a warning to the driver.

f. **Advanced Bus Information System**
This system provides bus arrival and departure information as well as controlling the bus route system.

2.2. Vehicle to Infrastructure (V2I)

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OBU can be gadget, radio transceiver, GPS and several other applications. The point is OBU can use anything important to communicate with RSU. RSU also consists of a radio transceiver that can communicate both ways with OBU devices in the vehicle. The RSU obtains data on the speed, time and location of the vehicle so that information will be sent back to the OBU device contained in the vehicle. This information will arrive if the vehicle is still within RSU coverage. Public Hospital will be placed in the infrastructure area at a certain height in accordance with equipment specifications. RSU can help the driver to make a decision in driving.

2.3. Power Received

In the communication process, it is important to analyze the power factor received by the devices on the V2I communication system. The power level determines the performance of the device. Based on research, amount of power (P) in the condition of Line of Sight (LoS) can be calculated based on Equation 1.

$$P_r = \frac{P_t G_t G_r}{L_{(rd)}} \left[D_d \left(\frac{\lambda}{4\pi r d} \right) + D_r \left(\frac{\lambda}{4\pi r} \right) \eta e^{-j\{k(r_d - r_r) + \emptyset\}} \right] \quad \text{...........(1)}$$

Information:

P_r = power received.
P_t = power sent.
G_t and G_r = gain of sending and receiving antennas.
λ = wavelength of signal propagation.
r_d = direct wavelength.
r_r = wavelength reflection of the signal.
φ = phase during wave experiencing reflections from the ground.
η = ground surface coefficient.
D_d and D_r = antenna directivity coefficient.
$L_{(rd)}$ = absorption factor.

3. Research Methodology

The stages of the research including 3 main stages, namely: hardware and communication design, localhost-based information design and data measurement and monitoring [9]. This stage is done serially. Beginning with the design (design) of the hardware that was built using a microcontroller module. This hardware is designed to be able to function as a Transceiver (Sender and Receiver). This device plays an important role in the V2I communication system and is known as the RSU (Roadside Unit).

Furthermore, to facilitate communication with users, a localhost-based information system is created. Measuring are taken of the parameters that support the performance of the device such as power, distance and height of the hardware. For more details, can be seen in Figure 1.

Figure 1 Stage of Research

3.1. Hardware and Communication Design

RSU device is built based on the ESP32 microcontroller. This module is a chip that is integrated into Wi-Fi and Bluetooth as well as the Internet of Things (IoT) application. ESP32 has been commonly used because of its low price, low power consumption, can be connected to an amplifier antenna and low noise [10].

In this study, ESP32 module is set as an access point. The wireless network standard used is 802.11 b / g / n with frequency of 2.4 GHz. To increase its range, RSU was added to a signal amplifier antenna. The amplifier antenna can improve the performance of RSU devices in the form of enlarging the coverage area, strengthening power and throughput [11].

The power source for the RSU device is the battery. The battery is charged by solar panels from the conversion of solar energy into electrical energy. The solar panel used is a type of poly-crystalline with 50 WP of power [12]. The shape of the RSU device design as shown in Figure 2.

This RSU device is placed alongside a road and can communicate with OBU devices. The OBU device is a smartphone that is available to vehicle users. Users can connect to the RSU with how to activate the wi-fi mode then connect to the RS-wi-fi. In this condition, the user can communicate with the RSU device. For more details, the form of communication RSU to OBU can be seen in Figure 3.

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Figure 2 Design of RSU Device

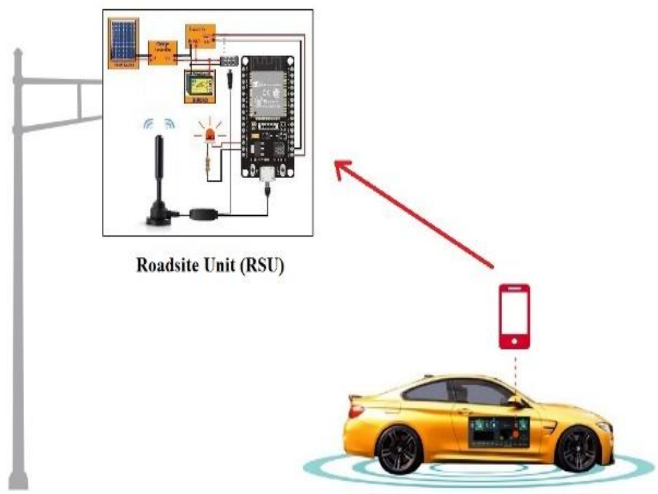

Figure 3 Form of Communication RSU to OBU

3.2. Localhost-Based Information Design

In this study, RSU device is built by ESP32 microcontroller and set up as an access point. In this way, RSU can conduct 2-way communication with users who are connected to it. Utilizing the integration of ESP32 microcontroller with Wi-Fi and Bluetooth, this step can be done easily.

Programming is done using the Arduino IDE emulator. The following is an attachment of the ESP32 microcontroller program code set as an access point.

```
#include <ESP32WiFi.h>
#include <WiFiClient.h>
#include <ESP32WebServer.h>

const char *ssid = "Smart Parking";
const char *password = "";
int milisInterval = 2000;
int count = 0;
ESP32WebServer server(80);
```

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```
void handleRoot() {
String html ="<!DOCTYPE html> <html> <body> <h1>AKSES BERHASIL</h1> <head><meta
http-equiv=\"refresh\" content=\"2\"><meta name=\"viewport\" content=\"width=device-width,
initial-scale=1.0\"></head> <div id=\"light\">";
html += LDRReading;
html +="</div><h1>Connected User</h1><div id=\"random\">";
html += count;
html +="</div> </body> </html>";
        server.send(200, "text/html", html);
  count++;
}

void setup() {
        delay(1000);
        Serial.begin(115200);
        Serial.println();
        Serial.print(" Random Number ");

        WiFi.softAP(ssid, password);

        IPAddress myIP = WiFi.softAPIP();
        Serial.print("AP IP address: ");
        Serial.println(myIP);
        server.on("/", handleRoot);
        server.begin();
        Serial.println("HTTP server started");
}

void loop()
{
        server.handleClient();
}
```

3.3. Data Measurement and Monitoring

The power received measurement scenario by OBU is carried out on the Polmed campus area. RSU equipment placed in the side of the road with a height of 3 m. The altitude is considered moderate / not too high so that the power received by the OBU remains maximum. This height is also adapted by the type of vehicle that passes in the campus area. The maximum height of the vehicle is 1.5 m. Very rarely large vehicles or a type of truck that passes on campus. The form of power measurement scenarios received by OBU can be seen in Figure 4.

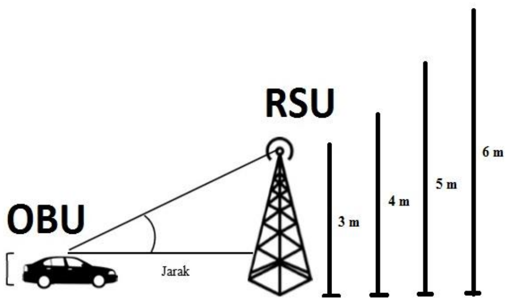

Figure 4 Power Measurement Scenarios

The parameters to be measured are power, height, and distance [13] [14]. The power level received by the OBU can be measured using a wi-fi analyzer. This application can be downloaded for

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free through PlayStore and installed easily. The display form of the wi-fi analyzer application as shown in Figure 5.

Figure 5 Wi-fi Analyzer Application

4. Analysis

The result of RSU design which was built based on the ESP32 microcontroller as shown in Figure 6. Next, measurements were made using vehicles that are moving away from the RSU device. The user activates the smartphone's wi-fi and connects it to the RSU's wi-fi. Then open the wi-fi analyzer application to measure the received power level. Based on the measurement results, the optimal distance from the RSU to the OBU is 90 m. From this distance, a power of -91 dBm is obtained. This value is the minimum signal sensitivity that can be captured by the ESP32 microcontroller. The following are the results of measurements of the power received by OBU as shown in Table 1.

Figure 6 Design of RSU

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Table 1
Results of Power Received Measurement

Height of RSU (m)	Power Received (dBm)	Distance (m)
3	-42 dBm	10
3	-54 dBm	20
3	-59 dBm	30
3	-65 dBm	40
3	-70 dBm	50
3	-76 dBm	60
3	-84 dBm	70
3	-86 dBm	80
3	-91 dBm	90

After the OBU is connected to the RSU, the user can access localhost to IP Address 192.168.4.1 to open the information page. After opening the page, there is simple information in the form of the number of application users connected to the Wi-Fi RSU and the random number of vehicles. In the next study the random number of vehicle information will be used to detect the number of available car parks. The following is a form of localhost display as shown in Figure 7.

Figure 7 Form of Localhost

5. Conclusion

RSU (Roadsite Unit) device design using ESP32 microcontroller has been tested by measuring several parameters related to device performance, namely the optimal distance between the RSU and OBU, the optimal height of the RSU above ground level and the power received by the OBU based on the distance to the RSU.

Based on the measurement results obtained specification data from the RSU device that can be the basis for subsequent development. A robust and programmable RSU device will support a reliable V2I communication system. Therefore, in further research it can be developed to expand the RSU communication network by increasing the number of devices [15] and for the application of detecting the availability of parking (smart parking) remotely. Utilizing the pin in / out of the ESP32 microcontroller for connection to the ultrasonic sensor as a detector for the car park. Furthermore, the ESP32 microcontroller can communicate with users about the existence of an empty car park.

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