Performance Evaluation of ESP32 in Outdoor Links

Pedro Rendeiro, Jamile Leite, Lucas Silva, Marcos Silva, George Sales and Leonardo Ramalho

***Abstract*— The purpose of this paper is to evaluate WiFi performance of the ESP32 module in outdoor scenarios. This was done by measuring the received signal strength indicator (RSSI) at different point of a relatively open area, prone to possible sources of interference, in order to simulate a real-life usage situation. The results show that it is possible to use this device at distances up to 300m from the wireless access point. Based on the acquired RSSI values, the achievable data rate was also estimated for each point.**

***Keywords*— IoT, ESP32, WiFi, RSSI.**

I. Introduction

In the context of Internet of Things (IoT), ESP32 modules and WiFi networks (IEEE 802.11 b/g/n) are very popular choices for implementing systems. Some of its advantages are the low cost, high availability on the market and the great amount of resources for testing [1]. However, it is not clear to what extend this combination is suitable for outdoor applications.

There are some works that perform experiments to obtain this kind of information. Many of them involve the measurement of the received signal strength indicator (RSSI). Algorithms that use this metric to estimate location have proven to be advantageous because of their low cost, high coverage, and absence of requirements for hardware adaptations [2], [3]. Furthermore, along with Signal to Noise Ratio (SNR), RSSI is one of the main factors considered in the IEEE 802.11 handover process [4], [5].

II. System Description

An overview of the developed system to test WiFi performance of ESP32 can be seen on Fig. 1. In order to measure RSSI in different positions of an open area, a portable hardware was developed, which is composed of an evaluation board ESP32 DevKitC V4 and the GPS module NEO-6M. Both use external antennas, where the former uses an external WiFi omnidirectional antenna (3dBi of gain). The hardware is supplied by a battery to power the whole system.

Moreover, the off-the-shelf access point (AP) Action RF 1200 from Intelbras was used to connect the prototype to a local area network (LAN). This product is equipped with four omnidirectional antennas (5dBi of gain each). In this same

This work was developed as part of the project GImpSI - Gestão dos Impactos da Salinidade em Isolamentos with INESC P&D Brasil and Celse - Centrais Elétricas de Sergipe S.A., under the framework of the R&D Program of the Brazilian Electricity Regulatory Agency, code PD-11278-0001-2021.

P. Rendeiro, J. Leite, L. Silva, M. Silva and L. Ramalho are with INESC P&D Brasil and the Department of Computer and Telecommunications Engineering of the Federal University of Pará (UFPA), Belém-PA (e-mails: [pedro.rendeiro, jamile.leite, lucas.damasceno.silva, marcos.lima.silva]@itec.ufpa.br, leonardolr@ufpa.br).

G. Sales is with Centrais Elétricas de Sergipe S.A. (CELSE), Aracaju-SE (e-mail: george.sales@celse.com.br).

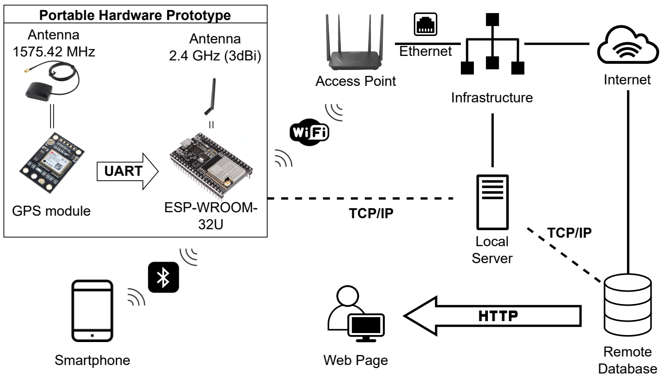

Fig. 1. System model with portable hardware prototype and software employed.

LAN, a local TCP/IP server was installed. The server is responsible for receiving the data from the prototype and sending it to a non-relational database called Realtime Database, which is part of the Firebase development platform. The samples and its locations can be retrieved by its administrators and are made available through HTTP request in a web page for any user.

It is also used a smartphone to trigger and monitor every RSSI measurement via Bluetooth serial communication. It must be said that Bluetooth is disabled before each measurement made, otherwise the measurement could be compromised, as they could cause interference in each other [6].

III. Test Execution

The executed test consists of fixing the AP on a given location, walking with the prototype in straight line in a given area to collect data periodically and sending it to the database through the network. The AP was positioned in the parking lot of the Guamá Science and Technology Park at a height of approximately 3.7 m, and the data capture hardware was moved within its range at a height of 2 m along the path. Besides, the antennas between AP and hardware had almost direct sight to each other during the whole execution of the test.

There were four pieces of data collected: latitude, longitude, timestamp and RSSI of the WiFi Network. When triggered by Bluetooth, ESP32 collects the location of the GPS module via the UART interface, captures the RSSI of the WiFi network that is connected and, over that same network, it sends both pieces of data to the TCP/IP local server along with the timestamp, which is collected through the network in the datetime formate (*yyyy-mm-dd*T*hh-mm-ss*).

IV. Results and Discussion

A total of fifty samples were collected during the tests. To better visualize this data, we built a web application that

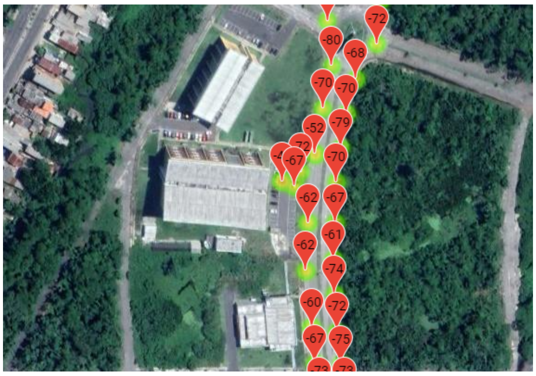

Fig. 2. Web application developed, in order to show the captured RSSI.

consumes the data stored in Firebase Realtime Database and displays it in a map (Fig. 2). Furthermore, we export the data to visualize the RSSI and the achievable data rate versus the distance, as shown on Fig. 3. The results indicate that the ESP32 module is capable of communicating at distances as high as 300 meters when a line of sight is available. In the area where the tests were performed, it was not possible to place the portable hardware at distances higher than 300m with line of sight.

In our tests, the minimum and maximum RSSI values obtained were -89 and -46 dBm, respectively. As expected, the RSSI tends to decrease as the mobile node moves away from the AP as shown in Fig. 3. The outdoor tests performed by [5] resulted in a graphic that decays much faster. This difference seems to be related to the transmission power and the number of antennas of the transmitter. We use the off-the-shelf AP described in section II, whose maximum transmission power is 18 dBm [7]. These authors, on the other hand, used an ESP32-S2 module as AP, whose typical TX power ranges from 13.5 to 18 dBm [8], depending on the modulation and coding scheme (MCS). In addition, in our setup we use external antennas on the AP and in the ESP32 module, while in [5], the authors use PCB antennas on both AP and client. Thus, in our tests it is more likely that the RSSIs are higher in our setup for the same distance.

Another result shown in Fig. 3 is the achievable data rate in the wireless link, which was estimated for IEEE802.11b and IEEE802.11n configured with 20 MHz and long guard interval for MCSs 1 to 7. These results were estimated based on Table I, which shows the relationship between the technology, the corresponding achievable data rate and the minimum RSSI to use the corresponding configuration. The minimum RSSI for each configuration was captured from [9] and the achievable data rate for each one was captured from ESP-IDF documentation [10] for IEEE802.11n. In the case of the IEEE802.11b, the values of RSSI and data rate were captured from the datasheet of the ESP32. Based on these data, it would be possible to transfer data to ESP32 with data rate as high as 11 Mbps at distances of 300m.

V. Conclusion

In this paper, we give insight into the implementation of a low-cost IoT system for monitoring RSSI and coordinates captured by means of a GPS module, which are transmitted to a database over a WiFi network by means of an ESP32 microcontroller in an outdoor environment. It was verified that ESP32 can be used with WiFi networks in areas up to 300m in relatively open terrain without loss of connection.

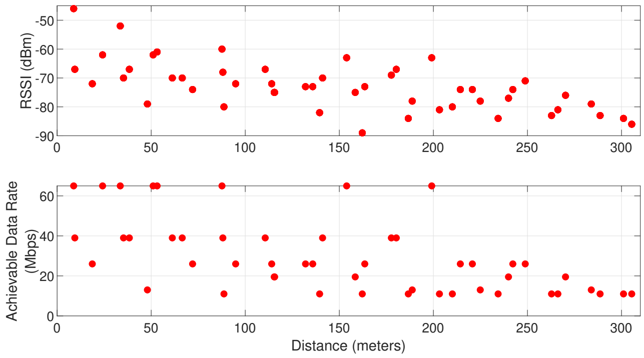

Fig. 3. RSSI and the corresponding achievable data rate versus the distance.

TABLE I

Minimum RSSI and data rate for different WiFi configurations

WiFi configuration	Data Rate	RSSI
IEEE 802.11b 1 Mbps	1 Mbps	-98 dBm
IEEE 802.11b 11 Mbps	11 Mbps	-89 dBm
IEEE 802.n HT20 MCS 1	13 Mbps	-79 dBm
IEEE 802.n HT20 MCS 2	19.5 Mbps	-77 dBm
IEEE 802.n HT20 MCS 3	26 Mbps	-74 dBm
IEEE 802.n HT20 MCS 4	39 Mbps	-70 dBm
IEEE 802.n HT20 MCS 5	52 Mbps	-66 dBm
IEEE 802.n HT20 MCS 6	58.5 Mbps	-65 dBm
IEEE 802.n HT20 MCS 7	65 Mbps	-64 dBm

References

[1] M. Babiuch, P. Foltỳnek, and P. Smutnỳ, "Using the esp32 microcontroller for data processing," in *2019 20th International Carpathian Control Conference (ICCC)*. IEEE, 2019, pp. 1–6.

[2] W. Xue, W. Qiu, X. Hua, and K. Yu, "Improved wi-fi rssi measurement for indoor localization," *IEEE Sensors Journal*, vol. 17, no. 7, pp. 2224–2230, 2017.

[3] U. Paul, R. Crepaldi, J. Lee, S.-J. Lee, and R. Etkin, "Characterizing wifi link performance in open outdoor networks," in *2011 8th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks*, 2011, pp. 251–259.

[4] L. M. Figueiredo and E. Franco Silva, "Cognitive-lora: adaptation-aware of the physical layer in lora-based networks," in *2020 IEEE Symposium on Computers and Communications (ISCC)*, 2020, pp. 1–6.

[5] V. Barral, O. Campos, T. Domínguez-Bolaño, C. J. Escudero, and J. A. García-Naya, "Fine time measurement for the internet of things: A practical approach using esp32," *IEEE Internet of Things Journal*, pp. 1–1, 2022.

[6] Espressif, "ESP-IDF Programming Guide: Coexistence," https://docs.espressif.com/projects/esp-idf/en/latest/esp32/api-guides/coexist.html, accessed: 2022-07-19.

[7] Intelbras, "Manual do Usuário: ACtion RF 1200," https://backend.intelbras.com/sites/default/files/2021-08/Manual-do-usuario-Action-RF-1200-02.20.pdf, accessed: 2022-08-01.

[8] Espressif, "ESP32-S2 Family: datasheet," https://www.espressif.com/sites/default/files/documentation/esp32-s2_datasheet_en.pdf, accessed: 2022-08-01.

[9] WLAN Professionals, "Laminated Card 802.11n/HT and 802.11ac/VHT | MCS, SNR and RSSI," https://wlanprofessionals.com/laminated-card-802-11n-ht-and-802-11ac-vht-mcs-snr-and-rssi/, accessed: 2022-06-30.

[10] Espressif, "ESP-IDF Programming Guide: Wi-Fi," https://docs.espressif.com/projects/esp-idf/en/latest/esp32/api-reference/network/esp_wifi.html, accessed: 2022-06-30.