VOL.39 Nº1 2022
https://doi.org/10.22491/IMECTA.10843.en

Hotspot mapping in outdoor environments

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ABSTRACT: The growing technological advances have contributed to the dissemination of new technologies, especially in the telecommunication area. The location of the devices is already ensured by the GPS service (Global Position System), with an accuracy of approximately three meters. However, the difference between the actual and the estimated position of some systems that only use the GPS service is insufficient, requiring a greater accuracy. Our study addresses a critical problem, specifically of geolocation and target tracking systems. We aimed to show a location algorithm in outdoor environments based on the strength of the received signal in which the system does not have the prior knowledge of the location of the routers, also known as Access Points (APs).

KEYWORDS: Access Point. Geolocation algorithm.

RESUMO: O crescente avanço tecnológico tem contribuído para a disseminação de novas tecnologias, principalmente na área de telecomunicações. A localização dos dispositivos já é assegurada, com um nível de precisão de aproximadamente de três metros, pelo serviço de GPS (Global Position System), porém a diferença entre a posição real e a estimada de alguns sistemas que utilizam apenas o serviço de GPS é considerada insuficiente, sendo necessária uma precisão maior. O trabalho proposto aborda um problema crítico, especificamente para sistemas de geolocalização e rastreamento de alvos. O principal objetivo é apresentar um algoritmo de localização em ambiente outdoor baseado na força do sinal recebido em que o sistema não possui o conhecimento prévio da localização dos roteadores, também conhecidos como Access Points (APs).

PALAVRAS-CHAVE: Access Point. Algoritmo de geolocalização.

1. Introduction

The technological advance of recent decades has been determining for the growing dissemination of new technologies and communication systems in society. This significantly increased wireless portable devices, which enabled the creation of geolocation systems for different reasons. The many uses of this type of system have stimulated the increase of research on location services and systems based on mobile devices.

According to [1], location systems and services are considered critical for specific use, such as search and rescue of victims of natural disasters.

This study aimed to develop an algorithm that offers the estimated location of an Access Point (AP) in real time, regardless of the standard communication protocol used in outdoor environments, using low-cost hardware that fits the three main conditions described by [2], which are:

- Functional - The algorithm must be easily detachable from the existing Wi-Fi (802.11) wireless network communication infrastructure without the need to change hardware or firmware and must only work with information already available in the APs, such as Received Signal Strength Indicator (RSSI) and Channel State Information (CSI).
- Universal - It must be able to locate any device that offers Wi-Fi (802.11) without requiring any other hardware from the target, such as accelerometers, gyroscopes, barometers, cameras, ultrasound, Bluetooth, etc.
- Accurate - It must be as accurate or more than the well-known location systems that use Wi-Fi signals (802.11), including those that do not meet the previous two requirements.

The Wi-Fi technology (802.11) is recent and has great potential as a supporting technology to the use that require mobility and flexibility, and its feasibility depends directly on locating methods, the complexity of the studied areas (indoors or outdoors) and the infrastructure technology, according to [3].

We organized this study in the following sequence: Section 2 discusses previous studies used as basis. Section 3 shows the platform used during the study. Section 4 addresses the methodology used, and section 5 shows the results. Section 6 shows the final considerations and suggestions for future studies.

2. Related studies

All previous studies faced the same challenge, which is to accurately estimate the location of the devices, even with the use of different techniques because of the effects on the Wi-Fi signal (802.11) and the intrinsic errors.

The RMCL algorithm [4] is based on the Monte Carlo algorithm to determine the position of moving targets, using RSSI information for the estimates. Despite evidencing the significant improvement in the accuracy of the location of the nodes by restricting a sample area, its focus is on mobile nodes, unlike our study. However, such as the signal propagation to estimate the RSSI values, it served as the initial basis of our studies since it used the shading model.

The FILA algorithm [5] uses the Channel State Information (CSI) technology with the Orthogonal Frequency Division Multiplexing (OFMD) modulation to estimate the location of the AP. The technique shows, with the aid of experiments, better accuracy than the use of RSSI, whose limitation is that reading is only possible for the OFDM modulations that are present in the 802.11a/g/n. standards. Therefore, if there is an AP with a different standard in the route, it will not be located.

The SpotFi algorithm [6] uses the AoA (Angle of Arrival), ToF (Time of Flight) and RSSI techniques, which estimate the probability of each pair of AoA and ToF of different multipath components to find the most likely location of the target that may have produced the captured RSSI and AoA. The use of this technique offered a mean accuracy of 50 cm; however, it was validated with a three-antenna Network Interface Card (NIC), restricting its use to insert the algorithm in any other hardware and obtain the same locating accuracy without additional components.

The ALPHA algorithm [7], which uses the ToA (Time of Arrival), RSSI and TDoA (Time Difference of Arrival) techniques, showed its best performance, with error < 3 m for more than 80% of the positions.

The algorithms found were insufficient for the three main conditions proposed by [2] to be universal, functional and accurate.

Tab. 1 - A comparative table between the addressed related studies.

Algorithm	Level of accuracy	Technique used	Negative point(s) in the use of the algorithm
FILA:	-	CSI and OFDM	OFDM modulations are not present in all Wi-Fi (802.11) standards. The determination of all targets in a new and unstructured environment is impossible.
SpotFi	50 cm	AoA, ToF and RSSI	Since it uses three-antenna NICs, it is not a functional algorithm.
ALPHA	< 3 meters	ToA and RSSI	Lack of accuracy in the result of the algorithm.
RMCL	-	Based on the Monte Carlo and RSSI location algorithm.	It only locates moving nodes.

3. Platform

The necessary infrastructure for the operation of the algorithm was prototyped using a Raspberry Pi 3 Model B microcomputer, a Wi-Fi (802.11) Universal Serial Bus (USB) dongle, Navio2, and the ARF DJI F450 kit as the basis of the UAV (Unmanned Aerial Vehicles).

3.1 Raspberry Pi

The Raspberry Pi is a low-cost, credit card-sized computer that connects to a computer or TV monitor and uses a standard keyboard and mouse [8]. Version 3 was chosen for the project mainly due to the improvement of data processing and because it has already integrated the Wi-Fi module (802.11), discarding the use of the Wi-Fi (802.11) Universal Serial Bus (USB) dongle.

3.2 Navio2

Navio2 is a board developed by Emlid for the creation of UAVs and built for research and education. It does not need multiple controllers when used with the Raspberry Pi board, which increases the strength of the project and facilitate the development.

3.3 Unmanned Aerial Vehicle

Initially designed for military purposes, UAVs are aircrafts that fly without the need of an onboard pilot.

The ARF DJI F450 kit was used in the project as the basis of the UAV, since it has an ultra-resistant material (ultra-strong PA66 + 30GF).

3.4 Unmanned Aerial Vehicle System

According to [9], UAVs require remote infrastructure for their operation since they do not have an onboard pilot, such as the components necessary to perform the taxi (route), takeoff/launching, flight and landing/recovery of the vehicle, the means necessary for the mission, the remote piloting station, software, means for communication and control, data links, loads, equipment for launching and recovery, maintenance and support.

3.5 Flight simulator and base station

The main software related to the development of autonomous flight platforms was studied, especially those on flight simulators and ground control stations (GCS). The FlightGear was chosen for the flight simulator because it is free and has open source, which allowed changes in the code to develop scientific research [1].

This infrastructure will allow the algorithm to be inserted in an autonomous UAV, which will fly over a controlled outdoor environment without human intervention. [1].

4. Proposed algorithm

The structure of the proposed algorithm was divided into two smaller algorithms that run in thread in the Raspberry Pi, and the first algorithm is responsible for the collection of GPS and RSSI data from the UAV, calculation of the estimated distance and validation from the signal quality. The second algorithm is responsible for the calculation of the estimated position using the trilateration concept (**Figure 1**).

In algorithm 1, the first step is the capture of GPS data by the Navio2 flight controller, which offers UAV latitude and longitude information in real time. Data capture is placed inside a loop to rotate until someone stops it.

Then, all available networks within the hardware range are scanned with the aid of the Wi-Fi library [11], which offers a set of tools to configure and connect Wi-Fi networks (802.11). Information for network identification (name and physical address), RSSI information and signal quality are captured.

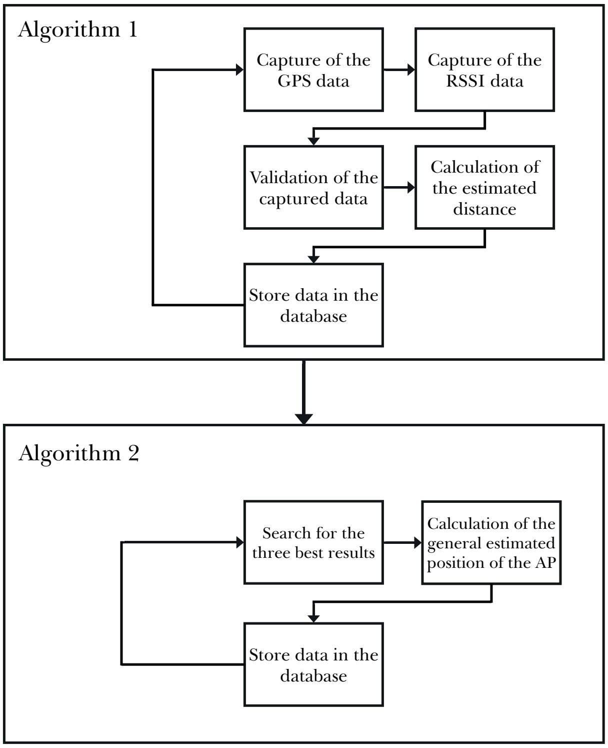

Fig. 1 - Structure of the proposed algorithm

Equation 1 is used to estimate the distance.

$$d = 10^{\frac{RSSI - RSSI_0}{-10n}} \qquad (1)$$

Such as:

- RSSI - Represents the value of the signal strength at a d distance in dBm.
- RSS_0 - Represents the value of the signal strength at one meter away in dBm.
- n - Corresponds to the path loss.
- d - Distance between transmitter and signal receiver in meters.

The literature shows few explanations of how to assertively obtain the RSS_0 value, therefore, a small experiment was conducted to verify if the RSSI readings show significant difference in case the equipment is close to or far from a large flat area, such as the soil. The tests to determine the n values (environment variable) and the RSS_0 value were conducted in two stages, in which the equipment was in direct contact with the soil and on top of a tripod. The experiment proved that the signal readings significantly improved when the routers and receiver were approximately 46 cm away from the ground, compared to the signal readings when the equipment was placed on the ground.

All read studies in outdoor environments attributed the value two to the constant n; however, no scientific experience was found that demonstrates which value is the best for the constant n.

To find the best n value, distance estimates were performed using the n values = 2, 2.5 and 3.

The combination that shows the smallest difference between the actual and the estimated distance happens when using RSS_0 equal to -30 dBm, n equal to 3, and when the equipment is not in direct contact with a large flat area.

This experiment enabled to determine from which values are validated by RSSI and quality, which showed that the error in the distance estimate was > 40 cm when the RSSI values were < -70 dBm and the signal quality was < 41. Therefore, it was considered that all captured signals with RSSI ≥ -70 dBm and signal quality ≥ 41 are valid.

The trilateration is estimated in the algorithm 2, which is a geometric method that allows to locate a point by the distance between that point and three other known points from the three best signals validated by the first algorithm, thus, the three signals with the highest RSSI values and signal quality are verified.

At this moment, geolocation data from distinct and non-coplanar points are used for the solution of the trilateration system equation (Eq. 2) [12] to show only a single result. If the trilateration result has two distinct points of intersection between the circumferences, the mean between the points is estimated. The result of the mean is the estimated location of the AP.

$$\begin{cases} d_{A1}^2 = \left(X - X_{A1}\right)^2 + \left(Y - Y_{A1}\right)^2 \\ d_{A2}^2 = \left(X - X_{A2}\right)^2 + \left(Y - Y_{A2}\right)^2 \\ d_{A3}^2 = \left(X - X_{A3}\right)^2 + \left(Y - Y_{A3}\right)^2 \end{cases} \quad (2)$$

Where:

- X and Y are the unknown coordinates;
- d_{An} indicates the distance from the mobile device to each station;
- X_{An} and Y_{An} are the coordinates of the fixed stations, with setting the reference for the A_1, A_2 and A_3 points.

Then, the mean of the longitude and latitude of the three coordinates with the best RSSI readings is estimated, as well as the mean between the result from the trilateration and the mean of the points of longitude and latitude.

All information obtained and estimated is stored in the database, which enables to have a history of all the values and results of the estimates at the end of the flight.

5. Results

We conducted all valid experiments in controlled environments, in open spaces, without movement of people and without large constructions, to compare the position estimated by the algorithm with the actual position. The only Wi-Fi signal sources (802.11) during the experiments were from the two devices used as network routers.

The two devices were a Samsung Note 8 cell phone and a TP-Link TL-WR702N Portable router (**Table 1**). We used two Wi-Fi network receivers (802.11), the receiver already present in the Raspberry Pi and a Wi-Fi Universal Serial Bus dongle (802.11).

Tab. 1 - Routers used to validate the proposal.

Router	Latitude	Longitude	Distance from the ground
Samsung cell phone	-22.95527°S	-43.16581°W	152.67 cm
TP-link TL-WR702N	-22.95535°S	-43.16580°W	75.40cm

We made 120 readings in the validation test of the proposal (**Table 2**), of which 83 readings were valid, that is, they have the RSSI ≥ -70 dBm and signal quality ≥ 41.

Tab. 2 - Number of readings for each router versus number of valid readings.

Router	Total number of readings	Number of valid readings
Samsung cell phone	60	36
TP-link TL-WR702N	60	47

The trilateration estimate used the three best reading values of each receiver (**Table 3**).

Tab. 3 - The three best valid readings of each router at the end of the experiment.

Receiver	Router	RSSI	Signal Quality	Estimated distance
Raspberry Pi Receiver	Samsung cell phone	-54 dBm	56	0.16 cm
		-55 dBm	55	0.15 cm
		-56 dBm	54	0.14 cm
	TP-link TL-WR702N	-51 dBm	59	0.20 cm
		-55 dBm	55	0.15 cm
		-67 dBm	43	0.06 cm
dongle	Samsung cell phone	-47 dBm	63	0.27 cm
		-61 dBm	49	0.09 cm
		-63 dBm	47	0.08 cm
	TP-link TL-WR702N	-41 dBm	69	0.43 cm
		-53 dBm	57	0.17 cm
		-62 dBm	48	0.09 cm

We estimated the mean longitude and latitude of the used readings and the value obtained from the trilateration based on the best values (**Table 4**).

Tab. 4 - Result of the solution proposed by the receiver.

Receiver	Router	Estimated latitude	Estimated longitude
Raspberry Pi Receiver	Samsung cell phone	-23.12075°S	-43.60682°W
	TP-link TL-WR702N	-22.86113°S	-43.35391°W
dongle	Samsung cell phone	-22.90689°S	-43.16517°W
	TP-link TL-WR702N	-23.42572°S	-43.86182°W

We noticed that the general mean error was 0.43669795 cm (**Table 5**).

Tab. 5 - Mean error between the actual position and the position estimated by the proposed solution.

Type of estimate	Mean error
By router	39.25 cm
By receiver	48.09 cm
Total mean error	43.67 cm

6. Conclusions

We aimed to create a functional, universal and accurate algorithm, capable of estimating the geolocation of APs without its previous knowledge.

We used known mathematical methods of distance and location estimates as solution for the created algorithm, assuming that the relationship between RSSI and the distance between APs is exponential, with a base equal to 10.

We concluded that the geolocation estimate of the APs can be satisfactorily performed if the algorithm can adapt to the environment in which it is incorporated.

The determination of the best data to be used in the estimates was one of the great difficulties. A deeper analysis, regarding runtime, on the performed readings that will be used in the estimates may improve the results. The concept of multilateration is another possibility, which consists of using more than three sets of captured values (Current position of the UAV at the time of reading and estimated distance value) for the geolocation estimate.

Acknowledgements

We thank the following institutions that enabled this study:

- CAPES (Coordination for the Improvement of Higher Education Personnel), for granting a master's scholarship by the Pro-Strategy Notice no. 50/2011;
- IME (Military Institute of Engineering), for granting us the honor of being part of the student board and being able to complete the Graduate Program.

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