Transactions on Engineering and Computing Sciences - Vol. 12, No. 2
Publication Date: April 25, 2024
DOI:10.14738/tecs.122.16746.
Mazimba, A. (2024). Mobile Equipment Tracking Based on Wi-Fi Technology: Case of An Open Pit Mine. Transactions on Engineering and Computing Sciences, 12(2). 70-82.



Mobile Equipment Tracking Based on Wi-Fi Technology: Case of An Open Pit Mine

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ABSTRACT

There are several positioning systems in the world which includes the commonly known GPS, GLONASS, BeiDou and Galileo. These happen to be satellite navigation systems. The paper presents a different approach of positioning using Wi-Fi access points. Most mobile equipment in open pit mines found in Zambia like Lumwana, Kalumbila and Kansanshi have Wi-Fi devices installed. These Wi-Fi enabled devices used for communication can be equally utilized for location tracking which would reduce on cost. In this study, three (3) access points were set up at 3 different locations in the line of sight of the mobile device. The access points provided the needed received signal strength indicator information (RSSI) for location tracking. A program to scan the RSSI information relevant to the position of the device was developed. Additionally, a server was configured to run mathematical computations that include distance estimations between the access point and the target device using the RSSI values received from the mobile device. The distance estimations were used for the trilateration. The trilateration gave the position estimation of the target device. The system results showed that RSSI measurements can be used to estimate the distance between the access point and the target device. Moreover, the coordinates from the trilateration were in the same range with the GPS coordinates.

Keywords: Wi-Fi, Distance, Trilateration, Location tracking, RSSI, Mobile device.

INTRODUCTION

Tracking of mobile equipment in a mine which is mostly a harsh environment increases the efficiency of mining operations and improves productivity [1]. It allows the mining dispatch team to remotely control and monitor the location of the mobile equipment. This cuts out idle time and any downtime which doesn't fully support the mining business. Besides that, tracking of mobile equipment usually facilitated by the GPS technology helps when it comes to planning for the mining haul roads. Beyond this, there has been an increase in safety for mining companies which are usually located in perilous environments. A stolen or damaged vehicle can be tracked and eventually recovered [2]. GPS technology being commonly known and considering the benefits it comes with, many mines are installing the GPS system on their mobile equipment for location tracking [3].

Wi-Fi Positioning System (WPS) also known as Wi-Fi Location Tracking under the bracked of Wi-Fi Technology may complement or substitute the commonly used GPS system and other

satellite navigation systems like GLONASS, BeiDou and Galileo [4]. Wi-Fi technology can operate in the same way the GPS technology operates [5].

GPS is limited in some areas with a lot of trees, enclosed buildings, tunnels and environments like underground construction sites. It doesn't work well because GPS satellite signals require a direct line of sight to multiple satellites [6], [7]. The Wi-Fi positioning system has been found to be one of the solutions that could deal with the GPS limitations [8]. The Wi-Fi positioning system takes the concept of the Global Positioning System to another level. Instead of relying on satellites, it uses Wi-Fi access points to locate Wi-Fi enabled devices [9]. Moreover, it has proved to be a low-cost solution to track assets [10]. This is because of its capability of being integrated with the existing Wi-Fi infrastructure which eliminates some hardware costs [11] . The idea of tracking devices using Wi-Fi technology can be extended to the mines because most mobile equipment in the mining industry is being equipped with Wi-Fi enabled devices for communication purposes. Lumwana, Kalumbila and Kansanshi open pit mines of Zambia have been observed to have Wi-Fi enabled devices installed.

LITERATURE REVIEW

Wi-Fi Technology

The generic Wi-Fi Positioning System architecture basically consists of 3 main components which includes the access points, the positioning server and the user interface as depicted in fig.1. Just like any other real-time location system, a Wi-Fi positioning system can use MAC addresses or IP addresses, signal strength and other methods to pinpoint a device's location. The range of Wi-Fi positioning can differ depending on factors such as whether you are using Wi-Fi access points or sensors or the nature of the environment. Wi-Fi operating at 2.4 GHz can be used in outdoor environments where adequate infrastructure is in place [12].

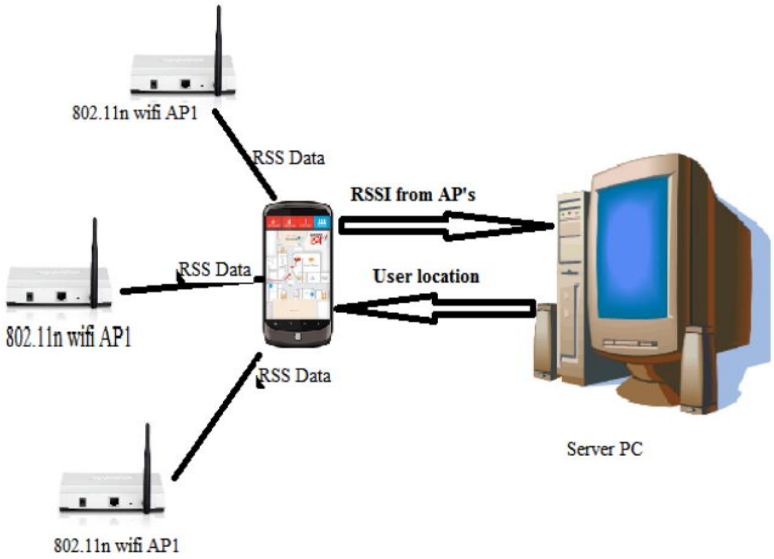


Figure 1: WPS Architecture [8]

There are multiple techniques of tracking a Wi-Fi enabled device using the Wi-Fi technology. The common ones include the Received signal strength indication (RSSI) techniques, Angle of

arrival (AoA) and the Time of flight (ToF)[13] [14]. The most used method is the Signal strength Indication (RSSI) technique. While these other methods are said to be more accurate, they require expensive equipment and methods such as multiple antennae and clock synchronization [15].

Using an RSSI-based method with multilateration is the most easily activated and low-cost option for Wi-Fi positioning [12]. Multilateration is a positioning method used to determine the position of an object by measuring the distance from three or more than three transmitters to a receiver as a terminal device. If three transmitters are used to determine the position of the receiver, then the system is known as a trilateration system [16].

Fingerprinting is also RSSI-based. Wi-Fi positioning with fingerprinting method involves using a database which records the location and signal strengths of surrounding access points. To create the fingerprinting database, a time-consuming calibration process is necessary which may need to be repeatedly performed. While actively tracking a device, the RSSI values are compared to the fingerprints in the database to estimate the prior trained device's location. With fingerprinting, the system needs to be calibrated regularly to reflect environmental changes. It is a low-cost method for Wi-Fi positioning but requires continuous updating to the trained Radio Frequency patterns in the database.

Distance Estimation

Distance estimation is foundational for the effective functioning of the Wi-Fi positioning System. Distance estimation can be done using a signal propagation model [17]. A signal propagation model helps to estimate the signal path loss and consequently the distance between the Wi-Fi device and the access point forming the basis for location estimation [18]. The estimated distance is a reliable location information.

Several distance propagation models are used for distance estimation. These include the free space path loss, log-distance path loss model, two-ray ground reflection model, Okumura-Hata model, and the Ray Tracing Model [19], [20] [21]. Each model has its strengths and weaknesses. The choice depends on the specific characteristics of the deployment environment for the Wi-Fi positioning system.

The commonly used signal propagation model in open outdoor environments is the Free space path loss. It is preferable when dealing with outdoor environments because it is a simple and effective model for estimating signal attenuation. The path loss is defined as the difference in decibels between the effective transmitted power and the received power and may or may not include the effect of the antenna gains [18]. The free space loss can be expressed in terms of the ratio of the radiated power (Pt) to power received (Pr) by the antenna or in decibels by taking 10 times the log of that ratio. For the ideal isotropic antenna, free space loss is given by.

$$FSPL = \frac{Pt}{\Pr} = \frac{(4\pi d)^2}{\lambda} = \frac{(4\pi d)^2}{c^2}$$

Where

- Pt = signal power at the transmitting antenna
- Pr = signal power at the receiving antenna
- λ = carrier wavelength
- F = carrier frequency
- D = propagation distance between antennas
- C = speed of light (3×10^8 m/s)

And d and λ are in the same units.

This can be recast in decibels as

$$FSPL(dB) = 10\log\frac{Pt}{\Pr} = 20\log\left(\frac{4\pi d}{\lambda}\right) = -20\log(\lambda) + 20\log(d) + 21.98dB$$

or [22]

$$FSPL(dB) = 10\log\frac{Pt}{\Pr} = 20\log\left(\frac{4\pi fd}{c}\right) = 20\log(f) + 20\log(d) - 147.56dB$$

You can use the free space path loss and the received signal strength indicator (RSSI) to estimate the distance between the transmitter and the receiver. The Received signal strength indicator (RSSI) value can be calculated by the following formula:

RSSI = Transmit power + antenna gain - path loss [23], [24].

The free space path loss and the received signal strength are inversely related. If the frequency of the signal is known and the RSSI measurements are available, the distance can be calculated. It should be noted that conditions such as interference and obstacles may affect the accuracy of distance estimation [25].

Position Detection Algorithm

A common approach in wireless positioning involves estimation of position in two steps. In the first step, position related parameters such as time-of-arrival (TOA), angle of arrival (AoA) and the received signal strength indicator (RSSI) are obtained. These provide information such as an estimate for the distance between the transmitter and receiver. Then in the second step, the position is estimated based on the signal parameters obtained in the first step. The second step constitutes the position detection algorithm which can be found by using geometric methods. Some commonly used geometric methods of the positioning process include triangulation and trilateration.

Trilateration is a geometric technique that uses estimated distances and involves solving a system of nonlinear equations to determine the coordinates of unknown positions as shown in fig.8 [26].

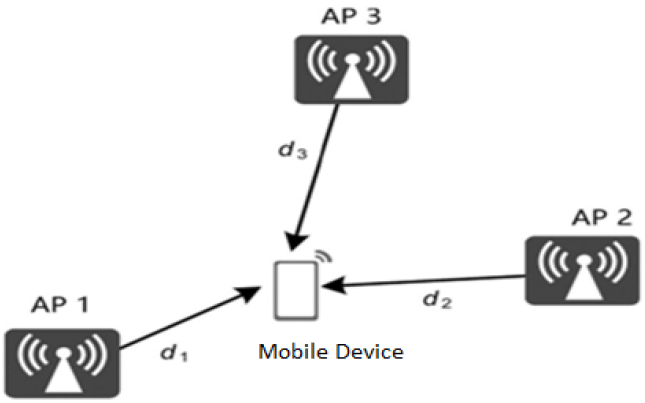


Figure 2: Trilateration Principle [24]

Considering AP1 has coordinates (x_1, y_1), AP2 has coordinates (x_2, y_2) and AP3 has coordinates (x_3, y_3), a simple solution can be achieved using Pythagoras theorem as follows.

$$d_1^2 = (x_1 - x)^2 + (y_1 - y)^2$$

$$d_2^2 = (x_2 - x)^2 + (y_2 - y)^2$$

$$d_3^2 = (x_3 - x)^2 + (y_3 - y)^2$$

Rearranging the equation above and solving for x and y, the desired coordinates of the target device can be obtained as shown below.

$$x = \frac{AY_{32} + BY_{13} + CY_{21}}{2(x_1Y_{32} + x_2Y_{13} + x_3Y_{21})}$$

$$y = \frac{AX_{32} + BX_{13} + CX_{21}}{2(y_1Y_{32} + y_2Y_{13} + y_3Y_{21})}$$

Whereby

$$A = x_1^{\,2} + y_1^{\,2} - d_1^{\,2}$$

$$B = x_2^{\,2} + y_2^{\,2} - d_2^{\,2}$$

$$C = x_3^{\,2} + y_3^{\,2} - d_3^{\,2}$$

And

$$X_{32} = x_3 - x_2$$

$$X_{13} = x_1 - x_3$$

$$X_{21} = x_2 - Yx_1$$

$$Y_{32} = y_3 - y_2 \quad [27]$$

$$Y_{13} = y_1 - y_3$$

$$Y_{21} = y_2 - y_1$$

Related Works

Wi-Fi technology in location tracking is gaining recognition due to the widespread availability of Wi-Fi. Moreover, the proliferation of Wi-Fi enabled devices such as smartphones, tablets and IoT devices have equally enhanced the potential for implementing Wi-Fi based location services [28]. In a study by Deepti Maduskar and Shashikala Tapaswi, the authors demonstrated how access points in a Wi-Fi network can be used to calculate the position of a mobile device. They developed a generic application to track the location of any person in any area, with adequate Access Points by comparing the Received Signal Strength (RSS) at his/her position with the already stored set of received signal strength from the dataset [11]. Furthermore, Alberto Diaz Velasco and Sergio Mellado Delgado designed and developed a system that combines the technologies of wi-Fi, location and Android with the implementation of an indoor positioning system. This developed system was able to obtain the position of any person inside a building with Wi-Fi coverage and display it on the screen of any device with the Android operating system in real time [29].

On the other hand, Anthea Wain carried out a study that involved received signal strength coupled with Wi-Fi technology for mobile device tracking. The received signal strength based wireless local area network indoor positioning and tracking system using comprehensive sensing on mobile devices developed by Anthea Wain yielded positive results [30]. Additionally, Auryn Pink Soderni explored the performance of three outdoor positioning algorithms based on Received Signal Strength measurements. The researcher noted that by using statistical coverage-area and path loss models, instead of the deterministic fingerprinting model, the size of the database is reduced significantly while the accuracy loss is negligible [31]. Other researchers who investigated on Wi-Fi technology in an outdoor environment were Binghao Li and Andrew G Dempster. They focused on the trilateration approach. They pointed out that the trilateration approach is relatively simple, a minimum of 3 base stations with known coordinates are required [32].

According to Peerapong Torteeeka, Xiu Chundi and Yang Donggkai, an indoor positioning system based on RSSI from wireless access equipment has become very popular in recent years.

This system is very useful in many applications such as tracking service for older people or customers inside living communities, mobile robot localization and logistic systems. Wi-Fi positioning system using the free bands like the 2.4 GHz does not require registration and does not usually require new infrastructure and the devices equipped with Wi-Fi technology can be reused. The mathematical model of wireless radio signal is a nonlinear function and the effects of the environment affect the signal which results in the system not being so accurate. Therefore, researchers are exploring the possibility of high accuracy, precision and robustness [33]. Md O Gani, Cassey O'Brien, Sheikh Iqbal Ahamed and Roger O. smith developed a mathematical model for estimating location of a mobile device using wireless technology which could be used indoors and outdoors. The RSSI based Indoor localization system for smartphone using fixed and mobile wireless nodes which was built showed good accuracy [34]. On the other hand, Xiayi Ye developed a wi-Fi positioning system based on fingerprinting called the Wifipoz which focused on improving the accuracy of the indoor positioning system. The system which was built proved that Wi-Fi technology was highly efficient both in accuracy and costs [35]. While the potential advantages of Wi-Fi technology are evident, studies also acknowledge challenges such as signal interference and environmental factors affecting signal strength. These findings underscore the for understanding of Wi-Fi's applicability and limitations in the context of open pit mining. A comprehensive review of technologies by R.M.M.R Rathnayake, Madduma Wellalage Pasan Maduranga, Valmik Tilwari and Maheshi B. Dissanayake showed that combining different technologies, such as integrating RSSI with machine learning algorithms, holds the potential to enhance accuracy and robustness in position localization solutions. The choice of technique should be based on specific application requirements, considering factors such as the desired accuracy levels, cost considerations and system complexity [36].

METHODOLOGY

To implement the Wi-Fi positioning system, there are several elements that need to be considered. These include the application programming Interface, the coordinate system, the distance detection algorithm and the position detection algorithm. The elements formed the designed system. In the designed Wi-Fi positioning system, the mobile device captures and sends the RSSI information from the respective access points to the server. The server is configured to run mathematical computations which include distance estimations using the RSSI values and trilateration using the estimated distances for position estimation.

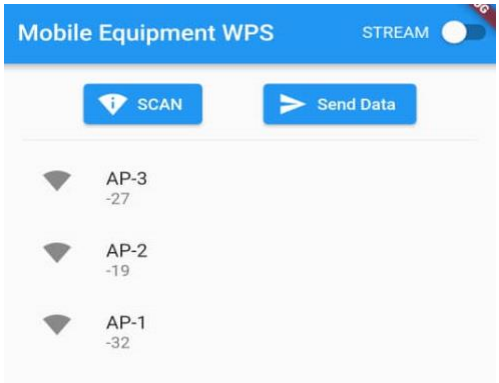


Figure 3: Developed Mobile Device WPS

It should be noted that the experiment was conducted in zone 35 in the southern hemisphere using UTM coordinates. Moreover, the designed mobile device application shown in fig.3 was programmed to only pick RSSI information from the access points which were set up as depicted in fig.4. Besides that, the distance propagation model used was the free space path loss.



Figure 4: Locations for the Access Points

RESULTS

Table 1[1]: RSSI Based Estimated Distance

Actual Distance between the access point and the target device in meters	RSSI value from target device in decibels	Estimated distance output from the designed system in meters
AP1		
<1	-36	0.322
5	-59	4.560
10	-67	11.455
20	-71	18.155
AP2		
<1	-29	0.144
5	-60	5.117
10	-69	14.421
20	-74	25.645
AP3		
<1	-28	0.128
5	-61	5.741
10	-66	10.209
20	-72	20.370

[1] This table shows the comparison between the actual measured distances using a tape and the RSSI-Based distance estimations.

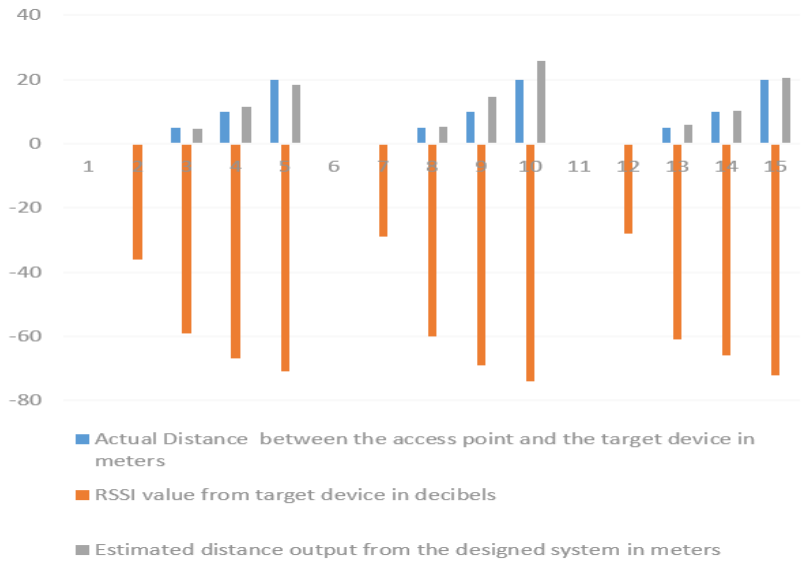


Figure 5: RSSI-Distance Relationship

Table 1 demonstrates that there are variations between the actual distances and the RSSI based estimated distances.

Table 2[2]: GPS Coordinates Vs Estimated WPS Coordinates

Location	GPS	WPS	Distance between the GPS and WPS Coordinates
Point 1	327215.166E 8648532.718N	327220.897E 8648531.654N	5.829
Point 2	327200.902E 8648532.743N	327204.306E 8648535.703N	4.511
Point 3	327191.146E 8648522.863N	327189.833E 8648521.865N	1.649
Point 4	327197.803E 8648513.695N	327191.870E 8648509.161N	7.349
Point 5	327218.324E 8648516.788N	327221.147E 8648512.021N	5.540
Point 6	327218.796E 8648523.388N	327215.924E 8648525.235N	3.415
Point 7	327208.865E 8648524.852N	327207.609E 8648525.667N	1.497
Point 8	327202.644E 8648521.77N	327202.736E 8648524.945N	3.176
Point 9	327207.508E 8648513.498N	327212.991E 8648508.605N	7.349
Point 10	327217.286E 8648519.609N	327216.7179E 8648521.0931N	1.589

[2] The table shows the comparison between the coordinates obtained from the GPS and the designed Wi-Fi Positioning System at 10 different points within the location of the access points which were set up.

The RSSI-Distance relationship plot in fig.5 shows that distance is inversely proportional to the Received Signal Strength Indication (RSSI). However, the relationship is somewhat nonlinear.

From table 2.

The mean of the distance between the GPS and WPS Coordinates = 4.202m

The median = 3.963

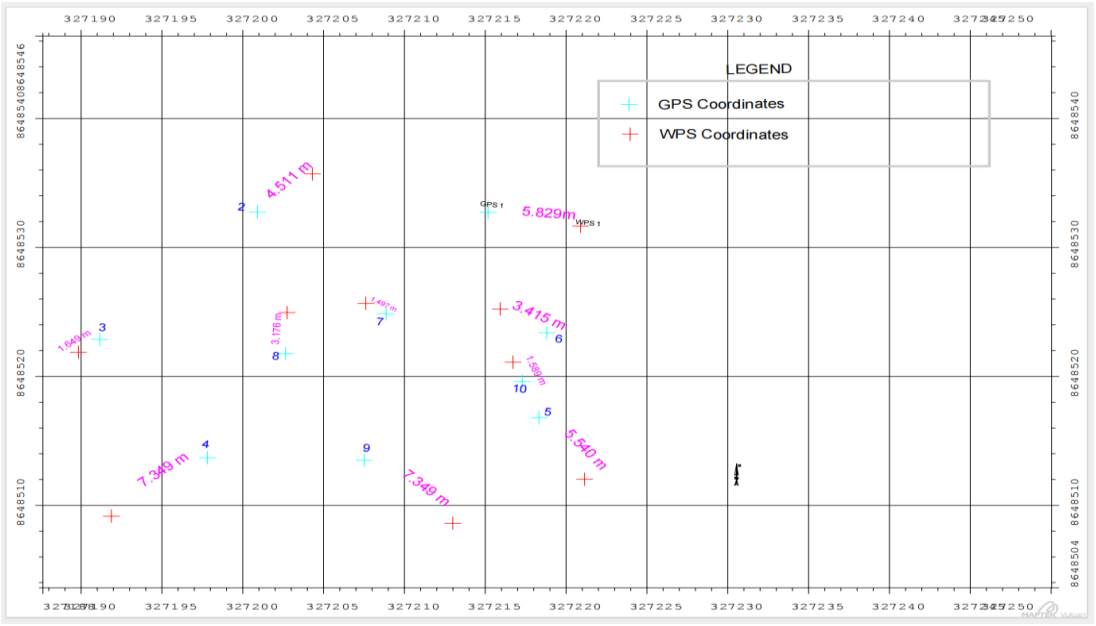


Figure 6: GPS Coordinates and Estimated WPS Coordinates on the UTM Grid

The designed Wi-Fi positioning system was evaluated by considering 10 positions in the study area. In the 10 positions, the GPS and the WPS coordinates were picked as depicted in fig.6. The mean difference between the GPS coordinates and the WPS coordinates was found to be 4.202m. This typically indicates that the designed Wi-Fi positioning system is relatively accurate and precise and can be used for mobile equipment localization.

CONCLUSION

RSSI values can be used to get distance estimations between the access point and the target device. However, there is room for improvement in the RSSI distance measurement techniques to reduce variability. The position detection algorithm highly depends on the distance estimations. Wi-Fi technology has the capability of using the RSSI distance-based measurements to obtain the position of the mobile device by using the trilateration algorithm. The distances between the GPS and the Wi-Fi positioning System results are not highly dispersed suggesting some degree of accuracy. Therefore, a simplified system like the one that has been designed would contribute to lowering the mining operational costs. However, tracking of mobile devices using Wi-Fi technology based on RSSI measurements alone does not give very accurate results.

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