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A Novel Hyperbolic Position Location Estimation in Wi-Fi Environments

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ABSTRACT
This article explores a new approach of localization using a novel hyperbolic method in an external environment. This method is compared with the conventional hyperbolic method. Two cases are considered: propagation in line of sight (LOS) and non-line of sight (NLOS) environments. The algorithm used here integrates a probabilistic approach which is centered on the rate of confidence. The analysis of the numerical results show that the new approach succeeds in delimiting the position of the target inside a geographically restricted area, even when the effective isotropic radiated power (EIRP) of the target is unknown. Our results are quite encouraging, because the proposed algorithm is able to obtain better localization results than comparative algorithms.

Keywords –Hyperbolic, LOS, NLOS, EIRP.

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I. INTRODUCTION

Positioning system technologies can be divided into two categories, namely, outdoor [1-3] and indoor [4-7] positioning. The most popular and established outdoor positioning system is the Global Positioning System (GPS) [2]. The current indoor positioning system technologies are Wi-Fi, Radio Frequency Identification (RFID) [4], laser, infrared, and ultrasound. Modern localization systems use various techniques and algorithms such as Received Signal Strength Indicator (RSSI) [1, 8], Time Of Arrival (TOA), Time Difference Of Arrival (TDOA) and Angle Of Arrival (AOA). GPS is well known to work independently, meaning the device does not require any installation of technology on a construction site, other than a resource on the device to position it for tracking service [1, 3]. RFID technology [1] enables a seamless link between any physical tagged entity and the business information infrastructure, providing lightweight computational and communication capabilities. Currently, the RFID technology that is used for personnel localization is actually only an attendance recording system rather than areal location tracking system. Using it, the exact position of the target cannot be determined, but only its location in a larger area. This does not satisfy the requirement of real-time, precision positioning. When the accidents happen in tunnels, for example, it would be very difficult to rescue the trapped workers because of low positioning accuracy. Wireless sensor networks (WSN) have attracted more and more research interest in tunnel applications for their advantages of self-organization, low cost, and high reliability [1, 6, 9]. Wireless sensor networks for location tracking would allow for a wide deployment of sensors across construction sites and, as a consequence, a chance for ubiquitous computing capable of implementing even complex applications such as integrated project monitoring to identify the real-time state of construction site activity.

With the development of IEEE802.11 technology, Wi-Fi has spread worldwide. Its coverage has increased more and more. Although Wi-Fi is not designed for positioning, the signal that access points (AP) or stations regularly send contains the radio signal strength information, which provides the possibility of locating the mobile station. Academia and industry pay close attention to applying Wi-Fi technology for location purposes. RFID has a history of demonstrated ability and market dominance, yet it also has a key disadvantage in the fact that it is currently populated with proprietary solutions, including expensive readers.

Compared with the existing positioning technology such as GPS, cellular localization, RFID, and ZigBee, positioning based on WiFi has the following advantages [10]: (1) it can work in different regions, such as indoor and outdoor, providing the possibility of ubiquitous positioning; (2) it only depends on the existing Wi-Fi network. It does not need to make any changes, and is of low cost, which means the existing IT infrastructure can be utilized; (3) the effect of non-line-of-sight (NLOS) on Wi-Fi signals is small, even in the situations where there are obstacles.

In this study, the positioning system based on Wi-Fi using RSS is introduced. We propose a new approach in order to localize a Wi-Fi Node.

The rest of this paper is organized as follows: In Section 2, the related works and research efforts are given. Description of the proposed technique is given in Section 3. The obtained results are given in Section 4. Finally, the conclusion is presented in Section 5.

II. RELATED WORKS

Currently, the majority of work [11-13] which has been undertaken in radiolocation by using the hyperbolic method estimates the coordinates of the target based on the time parameter. These hyperbolic techniques based on the TOA require a perfect synchronization between the clocks of the target and the receivers. That can be guaranteed only by the use of very expensive atomic clocks. There are also techniques which use TDOA [12, 13]. Here, the receiver sends a small pulse to the target and awaits an answer. The return time is proportional to the distance which separates it from the target. Research showed that the receivers can thus determine the location of the target when it can communicate with at least three receivers having fixed positions. In addition, the distance between the receivers and the target must be large in order to obtain good results. Recently, certain authors [14, 15] proposed the use of another parameter known in localization by the hyperbolic method: the power of the signal received. Marginalized for a long time in research due to its randomness, the power of the signal received is now more and more used in radiolocation. These authors show in principle that the losses are proportional to the distance between the transmitter and the receiver [14, 15]. To reduce the random side of the parameter, they proposed the idea to give a range of variation of the power of emission corresponding to a probability of reception of the signal [15]. The obtained results show that they are strongly influenced by the power of emission. This increases the uncertainties of the estimate of the coordinates of the target.

III. A NEW MATHEMATICAL MODEL FOR HYPERBOLAS

III.1. General question

In this section, we propose a new mathematical model based on the ratio of the transmitter-receiver distances between two receivers forming a pair of receivers. We assume that the power of the received signal, P_r, decreases by the loss value over the distance, PL, proportional to the distance to the transmitter as follows**:**

$$P_r = P_t - PL + G_t + G_r \ , \qquad (1)$$

where $P_t\,[P_t^-, P_t^+]$ is the power of the transmitter, $PL = \overline{PL} + X_\sigma$, $\overline{PL}$ represents the losses due to the distance covered by the signal with dependence on the environment, X_σ resides in the confidence interval [-zσ;+zσ], G_t and G_r are the gains of the radiating and receiving antennas, respectively.

III.2. Statement of the problem

Let us consider R_i, R_j, R_n and R_m as four probes forming two pairs of receivers (phones). d_i and d_j are the distances separating the transmitter T_x and the two receivers (Figure 1). We assume that the receivers are in the same environment.

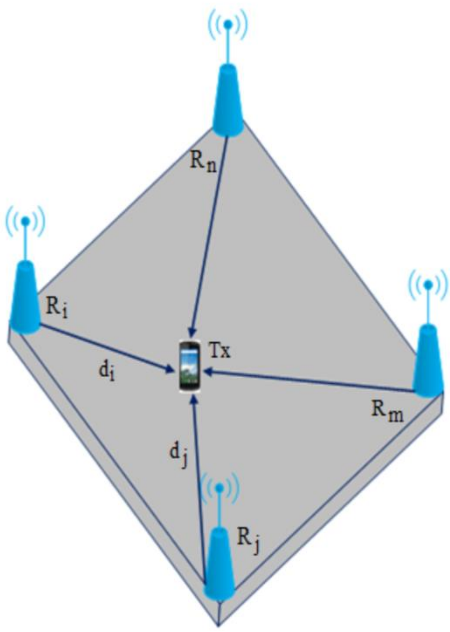

Figure 1. Geometry of the problem

By admitting that all the receivers are identical, i.e., having the same gain, and the phones of null gains, we have:

$$P_t = P_{ri} + \bar{L}(d_0) + 10 \cdot n \cdot log\left(\frac{d_i}{d_0}\right) \pm z\sigma, \qquad (2)$$

where $d_i = d_0 \cdot 10^{\frac{P_t - P_{ri} \pm z\sigma - \bar{L}(d_0)}{10 \cdot n}}$,
$d_i^- = d_0 \cdot 10^{\frac{P_t^- - P_{ri} - z\sigma - \bar{L}(d_0)}{10 \cdot n}}$ is the lower limit and
$d_i^+ = d_0 \cdot 10^{\frac{P_t^- - P_{ri} + z\sigma - \bar{L}(d_0)}{10 \cdot n}}$ is the upper limit and d_0 is a reference distance.

We next evaluate the range of variation of the distances between a pair of readers R_i and R_j (this is valid for the other pairs) limited by minimum and maximum data values by:

$$\Delta d_{i,j}^- = d_0 \cdot 10^{\frac{P_t^- - P_{ri} - z\sigma - \bar{L}(d_0)}{10 \cdot n}} - d_0 \cdot 10^{\frac{P_t^- - P_{rj} + z\sigma - \bar{L}(d_0)}{10 \cdot n}}, \quad (3)$$

and

$$\Delta d_{i,j}^+ = d_0 \cdot 10^{\frac{P_t^+ - P_{ri} - z\sigma - \bar{L}(d_0)}{10 \cdot n}} - d_0 \cdot 10^{\frac{P_t^+ - P_{rj} + z\sigma - \bar{L}(d_0)}{10 \cdot n}}. \quad (4)$$

By thus combining a pair of readers, we estimate the difference in distance between these two receivers. Then we build the hyperbolas limited by the minimal and maximum values given above. We thus obtain an equation of a pair of hyperbolas $H_{i,j}^-$ and $H_{i,j}^+$:

$$\Delta d_{i,j}^- \le \sqrt{(x - x_i)^2 + (y - y_i)^2} + \sqrt{(x - x_j)^2 + (y - y_j)^2} \le \Delta d_{i,j}^+ . \quad (5)$$

It is necessary here to restrict the surface of the initial zone in order to more rapidly home in on the target.

III.3. Solution to the problem

Greater distances generate greater uncertainties for systems of radiolocation in real time in targeted zones. To decrease these errors, we propose to use a ratio of distances which will generate min and max values that will be used to delimit the zone in which the target is by minimizing the errors.

Thus, we must calculate data from these terminals in the following way:

$$\min = \left(\frac{d_i}{d_j}\right)^- - \left(\frac{d_i}{d_j}\right)^+ \text{ and } \max = \left(\frac{d_i}{d_j}\right)^+ - \left(\frac{d_i}{d_j}\right)^-, \quad (6)$$

with $\left(\frac{d_i}{d_j}\right)^- = 10^{\frac{P_{rj} - P_{ri} - 2z\sigma}{10 \cdot n}}$ and

$$\left(\frac{d_i}{d_j}\right)^+ = 10^{\frac{P_{rj} - P_{ri} + 2z\sigma}{10 \cdot n}}.$$

It is seen here that the emission power no longer appears in the formula, showing that the calculation of the interval does not depend on it. It is necessary to note that the target is contained in the interval [min, max]. This interval will be used by the hyperbolic method to mark the differences between the hyperbolas generated by each receiver forming the pair. The technique admits a minimal number of four omnidirectional reception antennas, all deployed in external environments. The results below are based on the assumptions of the static radiolocation, i.e., that the target is in a well-defined zone.

IV. RESULTS AND INTERPRETATION

Figures 2a,b present the results of localization by the conventional method based on the RSSI in a LOS propagation scenario for a targeted surface of 100 m^2 with Wi-Fi technology. The values -52.75 dBm, -55.27 dBm, -55.27 dBm and -57.00 dBm represent the powers received by $R_i (i = 1)$, $R_j (j = 2)$, $R_n (n = 3)$ and $R_m (m = 4)$, respectively. Their Cartesian coordinates in meters are (4, 4), (14, 4), (4, 14) and (14, 14), respectively. The results were obtained with distance loss value of $n = 2.62$, a standard deviation of the signal attenuation $\sigma = 3.49$ and a rate of confidence of 92%. Initially, the localization of the target is carried out when the power of emission is in the range [-5, 20] dBm (Figure 2a). Figure 2b also presents the results for localization of the target when the emission power is in the range [0, 20] dBm. In view of this model and the obtained results, we note that the estimation of the position of a target depends on several parameters, namely, the emission power, the rate of confidence, and the rate of attenuation. Each parameter introduces an uncertainty which increases the error in the final phase of the estimation of the coordinates of the target. The results show that this conventional model is strongly influenced by the emission power and the rate of confidence. While varying the range of the EIRP and by using a rate of confidence of 92%, we obtain with the conventional method a smaller delimited zone but not containing the target.

Table 1 shows the results of tests 1 and 2 (numbers in red). Figure 2b, on the other hand, contains the target but with a delimited zone larger than Figure 2a. Test 3 shown in table 1 reveals that in certain cases the delimited surface can exceed the initial surface (numbers in blue). The various tests of Table 1 showed that the interval which gave the smallest surface is [-5, 20] dBm. That means that if we know the range of variation of the emission power, the conventional hyperbolic method is effective, particularly for countries having good regulations and high quality control of the material.

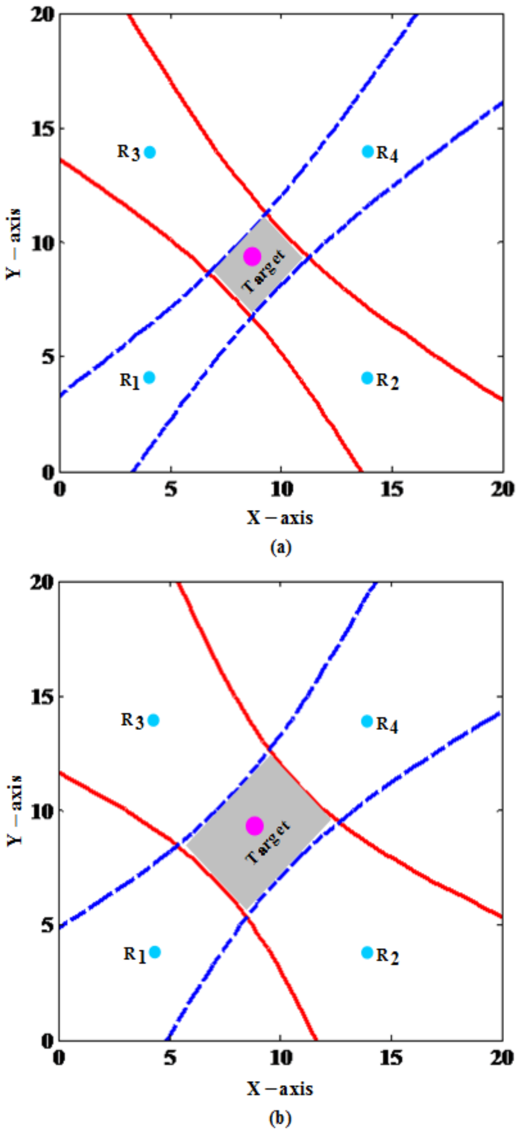

Figure 2.(a) Localization of a target by conventional hyperbolic method when the power of emission is located between [-5,20] dBm. (b)Here, the power of emission is located between [0,20] dBm. Both cases are for a LOS scenario with a rate of confidence of 92%.

The results of Figures 3a, b relate to the propagation in NLOS with the following parameters: the powers received byR_1, R_2, R_3 and R_4 are -64.3415 dBm, -66.3415 dBm, -65.3415 dBm and -67.3415 dBm, respectively. The Cartesian coordinates are the same as those of the Figures 2a, b. However, the distance loss value is $n = 3.63$, and the standard deviation of the attenuation of the signal is $\sigma = 5.73$, with the same rate of confidence as previously, including the same objective. The analysis of the numerical results shows that in NLOS as in LOS, we have the same conditions, with the difference that the target is present in all the cases. Moreover, we have three cases (numbers in blue) where surface generated by the method is larger than initial surface. The interval which gives the smallest surface in this case is [-10,20] dBm, as shown in table 2.

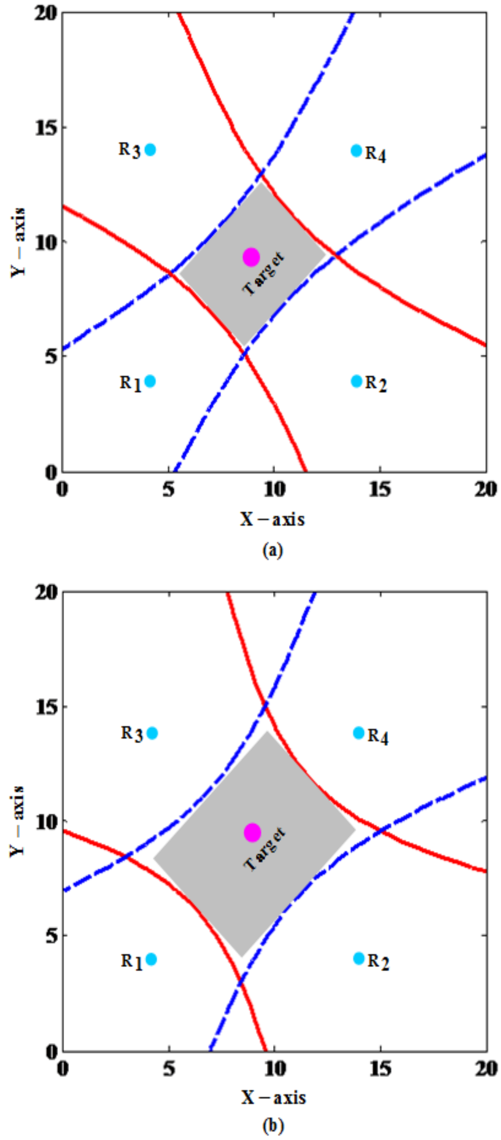

Figure 3.(a) Localization of a target by the conventional hyperbolic method when the emission power is located between [-5, 20] dBm. (b) Here, the emission power is located between [0,20] dBm. Both cases are for a NLOS scenario with a rate of confidence of 92%.

From these results we can conclude that the mathematical model of the conventional hyperbolic method based on the RSSI is dependent on the transmitted power of the target and the rate of confidence. We see that the precision of the hyperbolic method is better when the minimum power of emission is located in the interval [-10, -5] dBm, for either LOS or NLOS. In addition, when this power is in the interval [-∞, -10] dBm with the use of millimetre wavelength bands, the method is imprecise because the delimited zone generally does not contain the target. Lastly, when the minimum capacity of the EIRP is located in the interval [0, 5] dBm, the delimited surface exceeds the initial surface, as shown in Table 2.

Scenario LOS						
Power of emission in dBm	**Test 1**		**Test 2**		**Test 3**	
	Rate of confidence	**Obtained surface in m^2**	**Rate of confidence**	**Obtained surface inm^2**	**Rate of confidence**	**Obtained surface in m^2**
[-10; 20]	92%	3.9167	96%	5.5987	99%	8.6225
[-5; 20]		9.4072		13.4823		20.7645
[0; 20]		28.2233		32.4671		50.0035
[5; 20]		54.5532		78.1853		120.1452

Table1.Variations of the surface targeted according to the range of the emission power and the different rates of confidence in LOS.

Scenario NLOS						
Power of emission in dBm	**Test 1**		**Test 2**		**Test 3**	
	Rate of confidence	**Obtained surface in m^2**	**Rate of confidence**	**Obtained surface in m^2**	**Rate of confidence**	**Obtained surface in m^2**
[-10; 20]	92%	13.6245	96%	20.3815	99%	32.9900
[-5; 20]		25.6920		38.4340		62.2132
[0; 20]		48.4420		72.4769		117.3190
[5; 20]		91.3609		136.6716		221.2338

Table 2.Variations of the surface targeted according to the range of the emission power with different rates of confidence for the NLOS scenario.

Figures 4a,b present the results for the localization of a target in the LOS and NLOS propagation scenarios, using the new approach described above. The simulation parameters are the same as those used by the conventional approach using the hyperbolic method. The analysis of the numerical results shows that the new approach gives better results in terms of the reduction of the targeted surface, as shown in Table 2. It is clear that the non-dependence of the hyperbolic method on the EIRP makes it better in the sense that it is only influenced by the rate of the confidence. Moreover, the results for LOS show that the best rate of confidence is 92% for the new approach because we obtain the smallest surface with this rate. It is necessary to note that this approach is useful for systems of radiolocation in real time, having particular application in emergency services and catastrophe management in well-targeted zones, or where a prompt answer is required.

Compared to Tables 1 and 2, Table 3 shows that the new approach reduces the targeted surface as much as possible. Let us note that in both LOS and NLOS we have the same results. Nevertheless, the results are better with this approach, as shown in table 3. In other words, eliminating dependence on emission power allows one to better locate an object in a targeted zone. The use of the ratio to determine the distance from transmitter to receiver takes into account the environmental disturbances that can degrade the power of the received signal. In comparing Tables 1, 2 and 3, we also note that the new approach reduces the initial surface to an average of 84% and 78%, respectively, for both LOS and NLOS, compared to the conventional approach, which gives 60% and 27%.

Rate of confidence	Obtained surface in LOS	Obtained surface in NLOS
92%	8.4192	10.5142
96%	13.9137	18.2849
99%	26.1611	37.1826

Table 3.Variation of the surface according to the different rates of confidence for both LOS and NLOS. The unit of the obtained surfaces is in square meter.

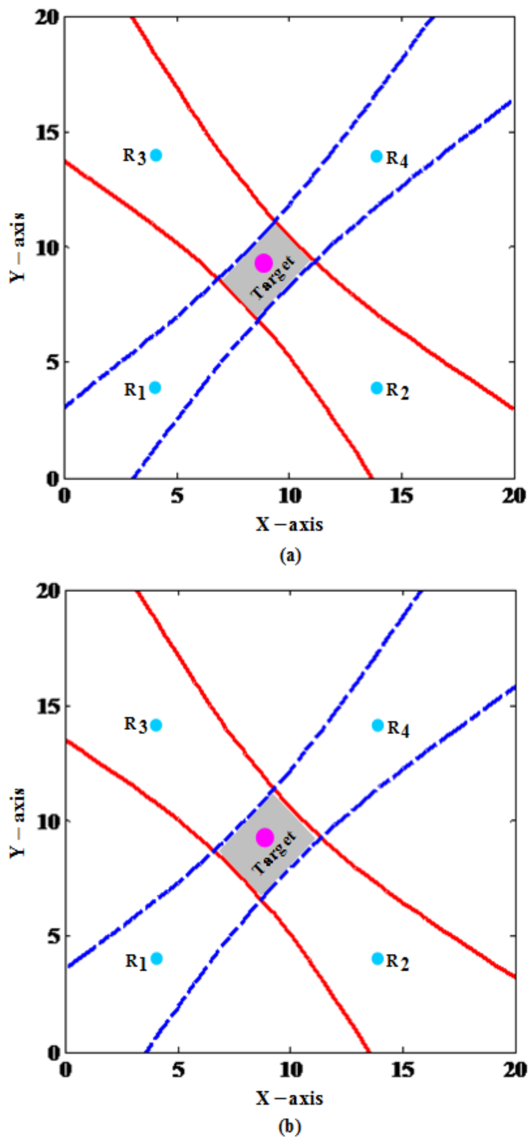

Figure 4.Localization of a target by the new hyperbolic method in (a) LOS and (b)NLOS scenarios. The rate of confidence used is equal to 92%.

V. CONCLUSION

In summary, we have solved the problem of radiolocation in an external environment by using a new hyperbolic approach. We showed on the one hand that the conventional method was dependent on the emission power. In addition, the non-dependence of the new hyperbolic method on the EIRP makes it better in the sense that it is only influenced by the rate of confidence. We can conclude that the advantage of this approach is to reduce the effects of variations of the propagation medium and the emission powers of the signals on the precision of the localization.

Lastly, although this method gave improved results, its effectiveness still remains to be checked with other technologies utilizing less of the low frequency band while under adverse conditions of propagation, such as in an urban environment.

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