Journal of Applied Sciences

ISSN 1812-5654

science
alert

ANSInet
an open access publisher
http://ansinet.com

Journal of Applied Sciences 14 (14): 1564-1569, 2014
ISSN 1812-5654 / DOI: 10.3923/jas.2014.1564.1569

Performance Comparison of UWB and Wi-Fi Based Indoor Localization Using TDOA

[1]R. Jayabharathy, [1]R. Varadarajan and [2]V. Prithiviraj
[1]Department of Electronics and Communication Engineering,
School of Electrical and Electronics Engineering, SASTRA University, Tamil Nadu, 613401, India
[2]Pondicherry Engineering College, Puducherry, Puducherry, 605014, India

---

Abstract: Location based services are becoming attractive with the deployment of next generation wireless networks and broadband wireless technologies. In this study an attempt is made to implement three dimensional Hyperbolic Position Location (PL) system using UWB and Wi-Fi wireless technologies. Generalized Cross Correlation (GCC) method is utilized to estimate the time delay and position estimation is obtained by range difference PL system, resulting in a set of non-linear equations. It is then transformed into linear equations using Taylor series. Finally comparison of performance between UWB and Wi-Fi based PL systems is analyzed in terms of Mean Square Error (MSE) for closure reference node densities. The proposed system is composed of wireless nodes (Receivers or Reference nodes whose positions are known), tags (Transmitter or Unknown position of the target) and location server to calculate the target position accurately.

Key words: TDOA, UWB, Wi-Fi, GCC, taylor series, MSE

INTRODUCTION

Basic problem in next generation wireless networks is Location awareness. Using GPS, localization has found application in many different fields (Jin *et al*., 2003). But it requires clear Line of Sight (LOS) to GPS satellite in order to estimate the user's location on the earth. However in the case of indoor and dense urban environments, the GPS signal is typically unavailable and localization becomes a more challenging problem. In such a situation Radio Frequency (RF) Position Location (PL) system gives solution to this problem (Zhang *et al*., 2010; Liu *et al*., 2007). It is generally classified into two categories as described in (Liberti and Rappaport, 1999).

Ranging, range-sum and range-difference systems are different classifications of Range based PL systems. Time Of Arrival (TOA) locates a transmitter by measuring the absolute or differential distance between receivers and tags (Jayabharathy *et al*., 2007). PL estimation of the transmitter is obtained at the point of intersection of multiple spheres with one of the receivers at the centre. This system has the limitation that it is not able to determine the exact time taken by the signal to travel from source (target) to the reference node (receiver), resulting in a bias term. Elliptical PL System measures the Time-Sum-of-Arrival (TSOA) of the propagating signal from user (source) to two reference nodes, to produce a range sum measurement. It describes an ellipsoid with foci at two receivers. Then the source position is estimated at the intersection of ellipsoids. Hyperbolic based PL system measures the TDOA of the signal propagating from the source to two receivers that are described in Liberti and Rappaport (1999). Then the PL estimation of the transmitter is obtained at the point of intersection of multiple hyperboloids. Hence it is also called as Hyperbolic PL systems (Jayabharathy *et al*., 2009). Figure 1 shows a 2-dimensional hyperbolic PL solution.

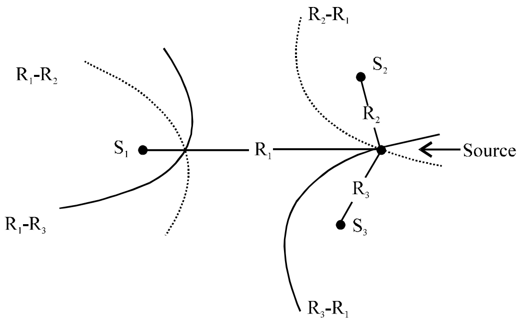

Fig. 1: 2D Hyperbolic PL solution

The advantages of Hyperbolic based PL system is described in Liberti and Rappaport (1999). Hence this proposed work is based on TDOA. This paper first describes the estimation of TDOA using GCC method. It

Corresponding Author: R. Jayabharathy, Department of Electronics and Communication Engineering,
School of Electrical and Electronics Engineering, SASTRA University, Tamil Nadu, 613401, India

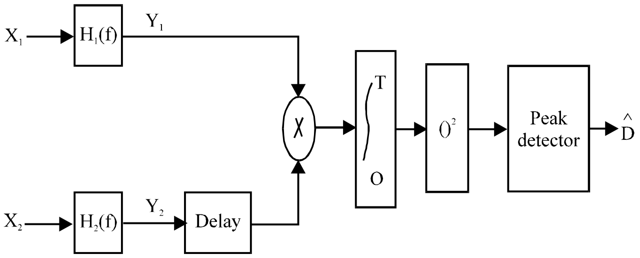

Fig. 2: TDOA estimated by GCC Technique

is then converted into time-Difference measurements between reference nodes. A set of non-linear hyperbolic range-difference equations is obtained. Exact location of the target can be obtained by linearising the set of non-linear equations using Taylor series (Liberti and Rappaport, 1999).

Next section discusses UWB Vs Wi-Fi for indoor localization, general model of TDOA estimation using GCC method, Hyperbolic PL estimation using Taylor series, Measure of PL accuracy using MSE and simulated results.

UWB vs WiFi for indoor localization:

- UWB has some advantages in the indoor localization
- UWB is coexistent with current narrow band and wide radio services
- It has large channel capacity
- UWB technology has the capability to work with low Signal-to-Noise ratio (SNR)
- Low transmit power
- Resistance to Jamming
- High performance in multipath channels
- Simple transceiver architecture

High resolution with improved accuracy can be obtained by using UWB technology. The Wide bandwidth available in UWB reduces interference to other systems and power requirement (Di Benedetto and Giancola, 2004; Gezici *et al*., 2005). This technology finds application in emergency services, patient tracking, asset monitoring, saving the lives of people during natural disasters like earth quake and tsunami.

Even though Wi-Fi offers several advantages in the indoor localization (Chai *et al*., 2011; Cypriani *et al*., 2010), it does not have much bandwidth i.e., bandwidth is forty times less than a UWB tag. Hence, Wi-Fi systems tend to transmit much more power. Increased power can help in contributing to greater accuracy.

The proposed system utilizes UWB/Wi-Fi based receivers and transmitter (Target). The position of the target is obtained using TDOA technique.

General model of TDOA estimation using GCC method: GCC, correlates the signal received by a reference node with another reference node described in Fig. 2.

This method correlates filtered version of the signal received by two reference nodes, then the peak of this cross-correlation estimates the TDOA between them. The filters H_1 (f) and H_2 (f) are used to reduce the interference before the signals are given as an inputs to the correlator (Liberti and Rappaport, 1999).

Consider a remote transmitter radiating a signal s (t) that is propagated through the UWB channel with noise is added in to it. Then the received signal of two UWB nodes X_1 (t) and X_2 (t) are used to estimate the time delay between them:

$$X_1(t) = A_1 s(t-d_1) + n_1(t)$$

$$X_2(t) = A_2 s(t-d_2) + n_2(t) \tag{1}$$

where, A_1 and A_2 represents the amplitudes of received UWB signal, n_1 (t) and n_2 (t) consist of noise and interfering signal, d_1 and d_2 are the signal delay times. Assume that the transmitted and noise components are jointly stationary, zero mean random process and are uncorrelated.

For $d_1 < d_2$:

$$X_1(t) = s(t) + n_1(t)$$

$$X_2(t) = A s(t-D) + n_2(t) \tag{2}$$

where, A represents the magnitude ratio of original received signal and its delayed version s (t) $D = d_2 - d_1$ is the time difference of arrival of s (t) between the two receivers. The selection of suitable receivers requires that estimation of amplitude scaling. The limit cyclic cross correlation and autocorrelation is:

$$R^{\alpha}x_1\,x_2\,(\zeta) = AR^{\alpha}s\,(\zeta\text{-}D)\,e^{-j\pi\alpha D} \qquad (3)$$

With $\alpha = 0$,

$$R^{0}x_1\,x_2\,(\zeta) = AR^{0}s\,(\zeta\text{-}D) \qquad (4)$$

- $R^{\alpha}x_1\,x_2\,(\zeta)$ is limit cyclic cross-correlation,
- $R^{0}x_1\,x_2\,(\zeta)$ is conventional limit cross-correlation

The argument ζ that minimizes Eq. 4 provides an estimate of the TDOA. Equivalently, Eq. 4 can be written as:

$$R_{x2x1}(\zeta) = R^{0}{}_{x2x1}(\zeta) = \int_{-\infty}^{\infty} x_1(t)x_2(t-\zeta)d\zeta \qquad (5)$$

Finite observation time can be required to estimate Rx_2x_1 (ζ). Then its estimated version is given by:

$$\hat{R}_{s2x1}(\zeta) = 1/T\int_{0}^{T} x_1(t)x_2(t-\zeta)d\zeta \qquad (6)$$

where, T represents the observation intervals.

Then Eq. 6 is represented interms of cross-power-spectral density function, $Gx_2\,x_1\,(f)$:

$$R_{s2x1}(\zeta) = \int_{-\infty}^{\infty} G_{x2x1}(f)e^{j\pi f\zeta}df \qquad (7)$$

The accuracy of delay estimate can be improved by filtering the original and its delayed version before integration. It is then fed to correlator, integrator and square blocks. This process is repeated for the different time shifts ζ, until the correlated output is attains a peak. Estimation of the TDOA having value D is caused by time delay due to the cross-correlation peak. This estimate is unbiased if the two filters are identical.

Hyperbolic PL estimation using taylor series: To locate a target in the 3-Dimensional (D) plane, consider a room with four fixed receivers. A person is entering the room, having a transmitter e.g., a UWB tag attached to the person's body. When the person enters the room the UWB tag transmits signal and all the four receivers receive the signal with some delay. Assume that all TDOA's to the first receiver (UWB node S_2) to be the first to receive the transmitted signal. Then let (x, y, z) be the remote source position and (x_i, y_i, z_i) be the known location of the ith receiver (Fixed reference node). The distance between the UWB/Wi-Fi tag (source) and the ith receiver is:

$$R_i = v\,(x_i\text{-}x)^2 + (y_i\text{-}y)^2 + (z_i\text{-}z)^2 \qquad (8)$$

Range-difference between reference nodes with respect to the first arriving UWB node S_2 is

$$\begin{aligned} R_{i,1} = c\zeta_{i,1} = R_i - R_1 = v\,(x_1-x)^2 + (y_i-y)^2 + \\ (z_i-z)\ \text{-}v(x_1-x)^2 + (y_1-y)^2 + (z_1-z)^2 \end{aligned} \qquad (9)$$

where, c represents the velocity of light, $R_{i,1}$ is the range-difference between the first UWB/WiFi node S_2 and i^{th} reference node, $\zeta_{i,1}$ is the estimated TDOA between the first reference node S_2 and i^{th} reference node. This defines the set of non-linear equations resulting in 3D coordinates of the source. Solving the set of non-linear equations for (x, y, z) is difficult. Consequently, linearising these equations is commonly performed by the use of Taylor series expansion and retaining the first two terms. It is computed by writing the first order approximation of the TDOA in Eq. 9 as:

$$R_{i,1} = R_{i,1}\,(x_v+\delta x,\ y_v+\delta y,\ z_v+\delta z) \qquad (10)$$

Taylor series solution is estimated in an iterative manner, where the current estimate of the source is (x_v, y_v, z_v). The true position is related to the estimated location by:

$$\begin{aligned} x &= x_v+\delta x \\ y &= y_v+\delta y \\ z &= z_v+\delta z \end{aligned} \qquad (11)$$

This measurement also contains inherent equipment-induced measurement error $e_{i,1}$. Then the error terms δx, δy and δz in the current estimated position can be expressed as a linear function of measured variables, calculated from the estimated position. Given a set of TDOA measurements between two or more pairs of reference nodes, along with a previous estimate of the UWB/Wi-Fi tags (x_v, y_v, z_v) and an estimate of the error terms $\{e_{i,1}\}$, it is possible to determine values of δx, δy and δz to update the estimated location (x_v, y_v, z_v) to more closely approximate the actual position (x, y, z). This process is repeated until the values of δx, δy and δz becomes smaller than a desired threshold, indicating convergence.

Measure of PL accuracy using MSE: The accuracy of the target positioning can be described in terms of MSE. It defines the squared distance between true and estimated position of the target. Thus in 3D:

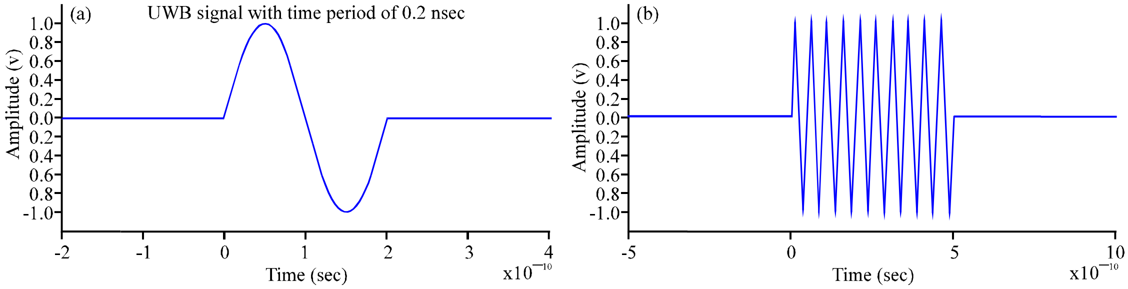

Fig. 3(a-b): (a) Transmitted UWB signal and (b) WiFi signal-frequency 2.4 GHz and time Period 0.5 nsec

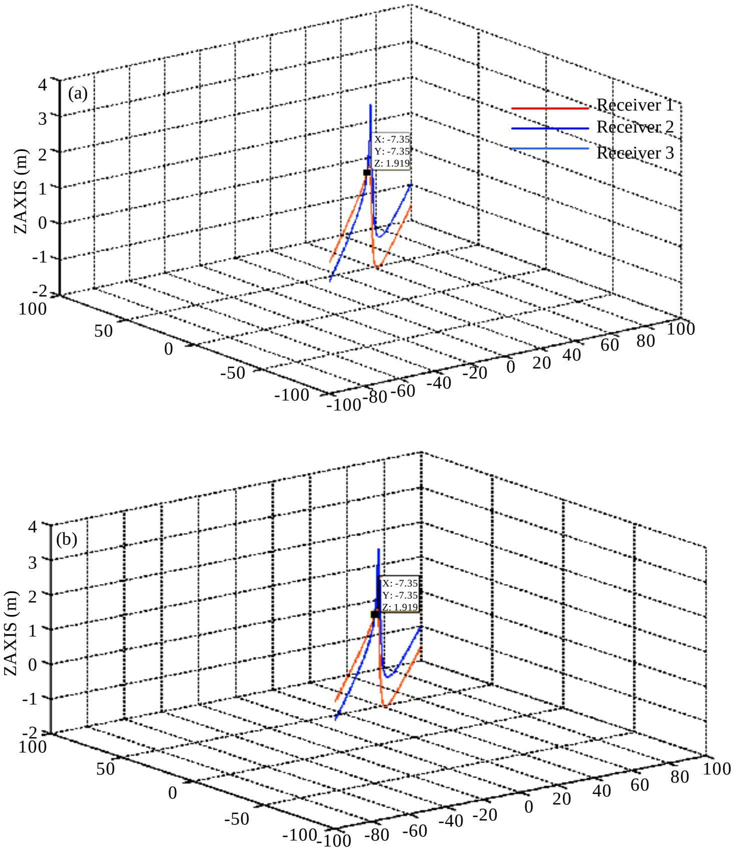

Fig. 4(a-b): (a) Intersection of hyperbolas (Target's Position) and (b) Intersection of hyperbolas (target's position)

$$\text{MSE} = E\,[(x-x_v)^2+(y-y_{v=})^2+(z-z_v)^2] \quad (12)$$

Let (x, y, z) and (x_v, y_v, z_v) be the true and estimated position of the target. E[.} denotes the ensemble average over all channel conditions.

PL system accuracy can also be expressed in terms of Root-Mean-Square (RMS) PL error. It is then denoted in terms of square root of the MSE.

$$\text{RMS Error} = v\ \text{MSE} \quad (13)$$

Simulation results: The UWB and Wi-Fi signal of 0.2 nsec and 0.5 nsec duration, respectively are simulated using MATLAB. Assuming that the transmitter output and receivers with delays of 0.1 n sec (S_1), 0.179 n sec (S_2) and 0.489 n sec (S_3 and S_4), respectively is shown in Fig. 3a, b.

Figure 4a and b, respectively shows the intersection of hyperbolas thereby giving the true position of the

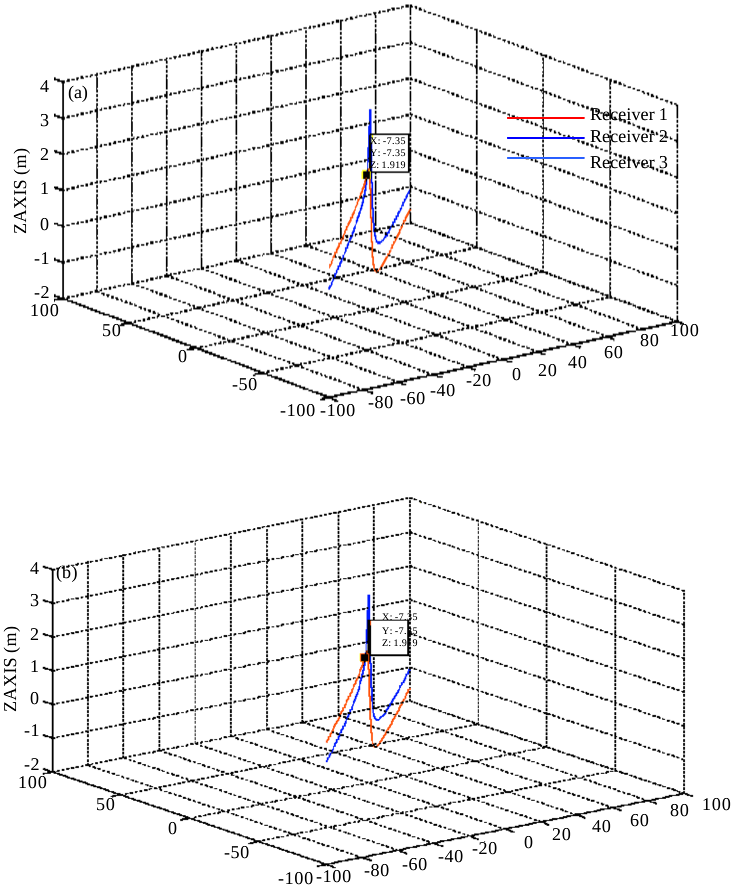

Fig. 5(a-b): (a) Intersection of hyperbolas (target's position) and (b) Intersection of hyperbolas (target's position)

Table 1: Methods giving the values of MSE and RMS

Methods	MSE values (m^2)	RMS values (m)
UWB combined		
	With TDOA 0.0200	0.1414
Wi-Fi combined		
	With TDOA 1.6220	1.274

target in 3D i.e., without noise added and estimated position of the target with random noise added using UWB radio link.

Similarly 3D WiFi based location of true targetposition and its estimated value are shown in Fig. 5a and b, respectively.

Finally comparison of performance between UWB and Wi-Fi based PL systems is analyzed using MSE. The MSE values for both UWB and Wi-Fi systems are are analyzed. From the Fig. 4a, b, 5a and b, the MSE value of UWB system is seen to be lower than that of the Wi-Fi system. Hence it is obvious that the UWB system offers a better performance than (Yang and Chen, 2009; Chandrasekaran *et al*., 2009). MSE and RMS values obtained for two different methods when the fixed nodes are close together and also to the target are given below in Table 1.

CONCLUSION

The present investigation uses the TDOA based positioning using UWB/Wi-Fi technologies. From the simulation results, it is observed that UWB radio offers a better performance in indoor wireless localization than Wi-Fi. The accuracy of the proposed system is better when it is combined with UWB. Also the resolution of multipath components makes it possible to find the target position exactly. TDOA estimation can be carried out with the help of Cross Correlation technique and Taylor series provides the exact position estimation of the target (source).

In future, it is proposed to use multidimensional scaling type of positioning system which increases coordinate dimension of the mobile source and thereby to achieve further improvement in locating mobile sources.

REFERENCES

Chai, W., J.H. Zhou, C. Chen, H. Nies and O. Loffeld, 2011. Localization and continuous indoor navigation based on low-cost INS/Wi-Fi integration. Proceedings of the International Conference on Indoor Positioning and Indoor Navigation, September, 2011, Guimaraes, Portugal.

Chandrasekaran, G., M.A. Ergin, J. Yang, S. Liu, Y.Y. Chen, M. Gruteser and R.P. Martin, 2009. Empirical evaluation of the limits on localisation using signal strength. Proceeding of Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Network, June 22-26, 2009, Rome, Italy.

Cypriani, M., F. Lassabe, P. Canalda and F. Spies, 2010. Wi-Fi-Based indoor positioning: Basic techniques, hybrid algorithms and open software platform. Proceedings of the 1st International Conference on Indoor Positioning and Indoor Navigation, September 5-17, 2010, Zurich, Switzerland.

Di Benedetto, M.G. and G. Giancola, 2004. Understanding Ultra Wibe Band Radio Fundamentals. 1st Edn., Prentice Hall, USA., ISBN-13: 9780131480032, Pages: 528.

Gezici, S., Z. Tian, G.B. Giannakis, H. Kobayashi, A.F. Molisch, H.V. Poor and Z. Sahinoglu, 2005. Localization via ultra-wideband radios: A look at positioning aspects for future sensor networks. IEEE Signal Process. Mag., 22: 70-84.

Jayabharathy, R., V. Prithiviraj, R. Varadarajan, P. Pavithra, P.M. Ruben Shyam and S. Anand, 2007. Context aware localization using kalman filter for UWB applications. Proceedings of the International Conference on Advances in Information and Communication Technologies, March 7-9, 2007, Hong Kong, pp: 17-21.

Jayabharathy, R., V. Prithiviraj, R. Varadarajan, V. Arvind, K.D. Murugan and S.J. Prabhu, 2009. Context aware TDOA based localisation using Kalman filter for UWB Applications. Proceedings of the International Conference on Intelligent Systems and Control, November 16-18, 2008, Orlando, Florida, pp: 13-13.

Jin, M.H., E.H.K. Wu, Y.B. Liao and H.C. Liao, 2003. 802.11 based positioning system for context aware applications. Proceedings of the IEEE Global Telecommunications Conference, Volume 2, December 1-5, 2003, Taipei, Taiwan, pp: 929-933.

Liberti Jr., J.C. and T.S. Rappaport, 1999. Smart Antennas for Wireless Communications. Prentice Hall, New Jersey, USA.

Liu, H., H. Darabi, P. Banerjee and J. Liu, 2007. Survey of wireless indoor positioning techniques and systems. IEEE Trans. Syst. Man Cybern. Part C: Appl. Rev., 37: 1067-1080.

Yang, J. and Y.Y. Chen, 2009. Indoor localization using improved RSS-based lateration methods. Proceedings of the IEEE Global Telecommunications Conference, November 30-December 4, 2009, Honolulu, USA., pp: 1-6.

Zhang, D., F. Xia, Z. Yang, L. Yao and W. Zhao, 2010. Localization technologies for indoor human tracking. Proceedings of the 5th International Conference on Future Information Technology (FutureTech), March 2010, Busan, Korea, pp: 1-6.