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Indoor Wireless Localization-hybrid and Unconstrained Nonlinear Optimization Approach

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Abstract: In this study, a hybrid TOA/RSSI wireless localization is proposed for accurate positioning in indoor UWB systems. The major problem in indoor localization is the effect of Non-Line of Sight (NLOS) propagation. To mitigate the NLOS effects, an unconstrained nonlinear optimization approach is utilized to process Time-of-Arrival (TOA) and Received Signal Strength (RSS) in the location system.TOA range measurements and path loss model are used to discriminate LOS and NLOS conditions. The weighting factors assigned by hypothesis testing, is used for solving the objective function in the proposed approach. This approach is used for describing the credibility of the TOA range measurement. Performance of the proposed technique is done based on MATLAB simulation. The result shows that the proposed technique performs well and achieves improved positioning under severe NLOS conditions.

Keywords: LOS, NLOS, RSSI, TOA using Generalized Cross Correlation (GCC), unconstrained nonlinear optimization, wireless location etc

INTRODUCTION

The usage of cell phones has risen exponentially in the recent past compelling wireless service providers to scrounge everyday for new technology to accommodate the enormous populations and to provide superior wireless location-based services. However the biggest challenge the wireless industry faces is to provide such supreme services while the user is in an indoor environment. The most eminent of all technologies used to locate the mobile in an indoor location is the radio location system that measures between the MS and a set of base stations (BSs), the location metrics of radio signals. The location metrics of this class, which is with respect to the handset or the network, depends on the magnitude of Received Signal Strength (RSSI), Time Difference of Arrival (TDOA), Angle of Arrival (AOA) and Time of Arrival (TOA) is described in Caffery and Stuber (1998) and Joseph Jr and Theodore (1999) Before the qualities of location metrics are assessed one needs to understand the parameters that play a vital role in altering it in indoor conditions. The first and the foremost factor is the line of sight between the mobile station and the bases station. When there is a LOS then the quality of the location metrics is precise and thus making the error computation simple. However in an indoor condition it is not possible to have LOS as there are several obstacles which may either deflect the radio wave or absorb it, impelling errors due to excess length, noise or a weak signal. The condition where one does not have a LOS is coined as NON LINE OF SIGHT; Abb. NLOS. Thus the error due to NLOS which gives rise to a dense multipath of signals influences the location metrics heavily (Wylie and Holtzman, 1996).

Considering the fact that the ensemble of MS is mainly located in an indoor condition, in this study, we propose for UWB radio link, a hybrid TOA/RSSI using unconstrained nonlinear optimization technique. The amalgam of the two was chosen so because:

- The UWB technology has high inherent delay resolution and ability to penetrate obstacles thus allowing high accurate ranging in the most unsuitable environment for range based localization (Gezici *et al*., 2005; Maria-Gabriella and Guerino, 2004)
- The UWB facilitates low power, high speed and indoor wireless communication.
- The knowledge of LOS/NLOS condition is unnecessary as the algorithm uses a previously established loss path model and RSS to distinguish between the NLOS/LOS conditions to establish a geometrically objective function between the BSs and TOA range circle.

Thus the algorithm while using only three TOA measurements using GCC caters to the needs of

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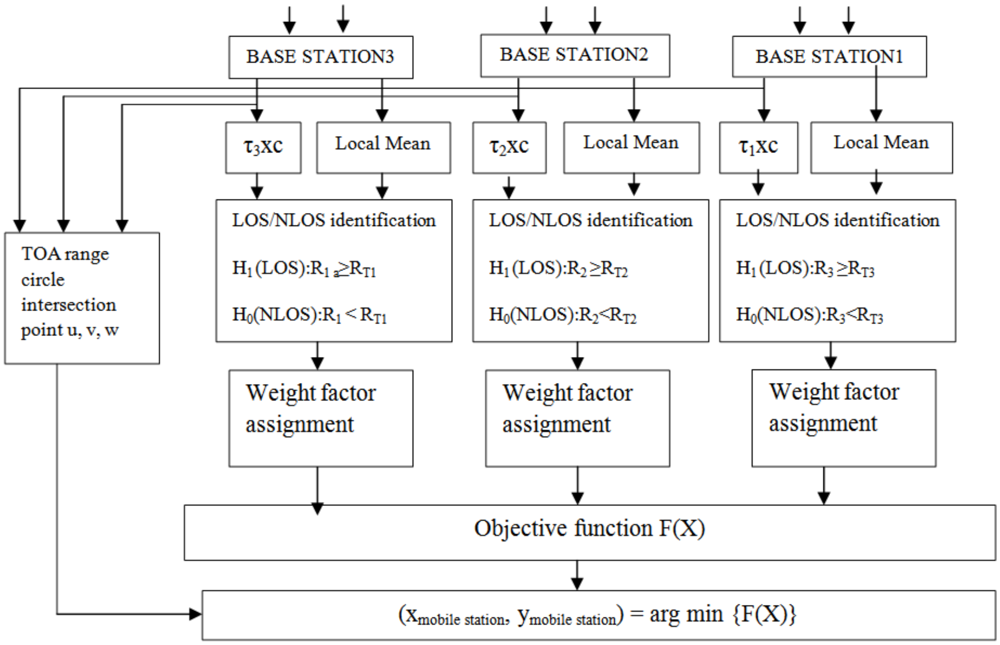

Fig. 1: Flow chart of hybrid TOD/RSSI wireless location algorithm

accurate measurement and ranging of the location metrics in a dense environment is described in Caffery (2000) and Venkatraman *et al*. (2004), which are prone to errors when used any other technology. The weight factors, used in defining the credibility of the TOA range measurements, were assigned based upon the results obtained from the hypothesis testing. These, during the process of location estimation, will influence the objective function. MATLAB has been used to perform simulation. Simulations were carried out to study the performance of the proposed technique for different scenarios of the NLOS errors.

The forthcoming sections discusses Hybrid TOA/RSSI wireless location algorithm, Nonlinear objective function, path loss model, LOS/NLOS BS identification, simulation results and conclusion.

Hybrid TOA/RSSI wireless location algorithm: In this study, a hybrid TOA using GCC/RSSI indoor wireless location using unconstrained nonlinear optimization technique is proposed for UWB radio. The Flow chart of hybrid GCC based TOA/RSSI Wireless location algorithm is shown in Fig. 1

The TOA which is also popularly known as the spherical PL system is the intersection of multiple spheres produced by multiple range measurements from multiple base stations. This provides an approximate estimate of the user. The algorithm in this study uses only three such spheres whose centre is the BS and radius is the product of TOA measurement and speed of light.

Assuming the t_i to be the time of arrival at each BS, calculated using GCC described in Joseph Jr and

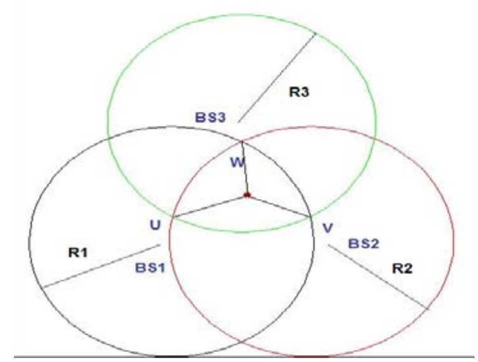

Fig. 2: Geometry of TOA-based location: Measurement range circles and the overlapped region in which the MS lies

Theodore (1999), the estimated range R_i corresponding to i[th] BS can be mathematically represented as:

$$R_i = c \times t_i \quad (1)$$

If there is no NLOS error and measurement noise the intersection of three TOA range circle will be the true MS position. The NLOS error is assumed to be largely positive, causing the measured ranges to be greater than the true ranges show in Fig. 2.

Nonlinear objective function: The actual ranges between the MS and i[th] BS can be mathematically represented as:

$$D = \sqrt{(x - x_i)^2 + (y - y_i)^2} \quad (2)$$

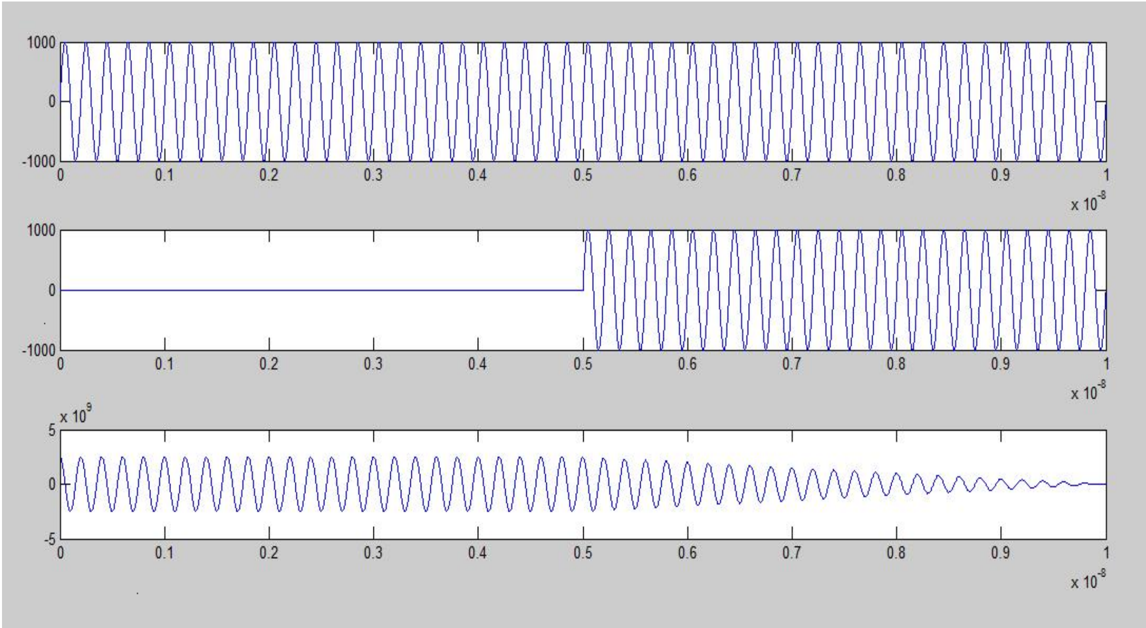

Fig. 3: Generalized cross correlator output

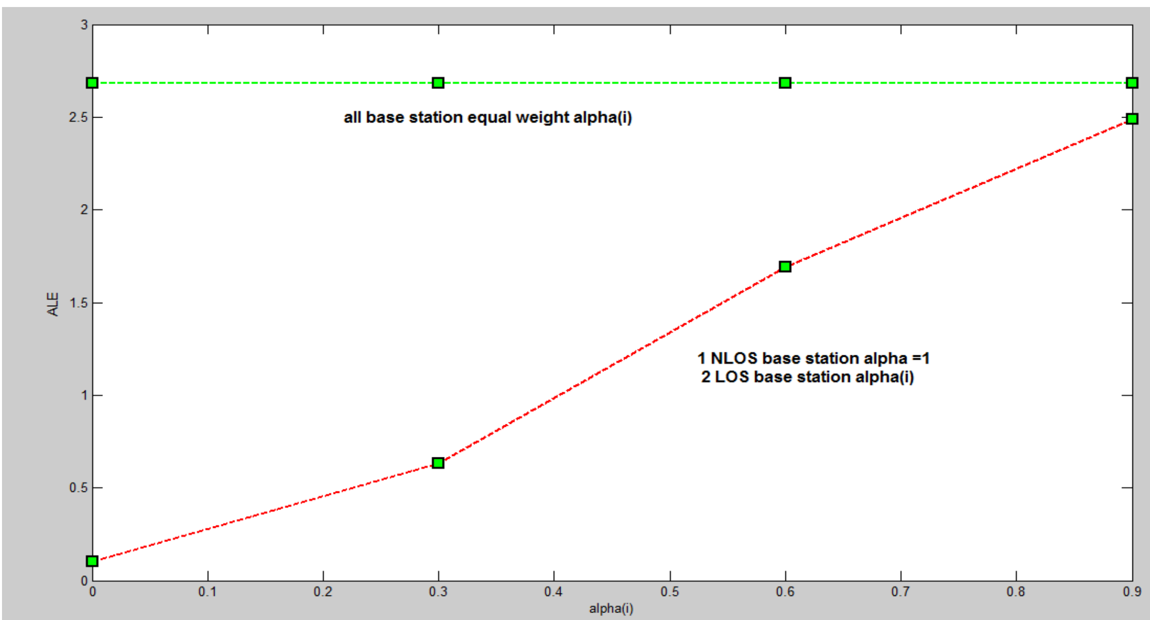

Fig. 4: Effect of weight factor in location algorithm

where,
(x, y) = The true position of MS
(x_i, y_i) = the location of i^{th} BS

Let P_i be the power measurement of received signal from the MS to the i^{th} BS and R_i be the TOA measurements. The objective function, in the presence of NLOS error can be established as the sum of weighted square errors:

$$F(x) = \alpha_1^2 \mid x - x_u \mid^2 + \alpha_2^2 \mid x - x_v \mid^2 + \alpha_3^2 \mid x - x_w \mid^2 \quad (3)$$

where $x = (x, y)^T$ is the estimated MS location vector x_u, x_v and x_w represent the position of points u,v and w respectively and the reliability of the signals are represented by the weights α_i. The corresponding range measurements in general are more reliable if the weights are smaller. Therefore by adjusting the weight that is correlates each intersection, the location error can be reduced by minimizing the objective function. Effects of different weight factors on the averaged Location Error (ALE) in the TOA algorithm for NLOS/LOS cases are shown in Fig. 4. The precision of the location valuation is improved when smaller weights are used and two BS's are of LOS.

Selected path loss model: The relationship between RSSI and distance is utilized to determine the values of weight factors and the corresponding distances from the Mobile Station to all Base Stations for a given RSSI, can be determined by the path loss model in a wireless transmission network. These parameters i.e. the path loss model RSSI are also utilized for estimating the transmitter-receiver separations, which are further used in LOS/NLOS identification. The flow chart of the hybrid TOA/RSSI wireless location algorithm is shown in Fig. 1

A general path loss expression that accounts for the reflection, diffraction and scattering for both LOS and NLOS path can be expressed as:

$$PL(d) = PL_0 + 10*\gamma*\log_{10}(d/d_0) + S \qquad (4)$$

where, PL_o is the mean path loss at the reference distance d_0 = 1 m, γ is the path loss exponent and S denotes zero mean Gaussian random variable with standard deviation σ (also in dB). This can be written a:

$$S = y\sigma \qquad (5)$$

where, y is zero mean, unit variance Gaussian random variables. The random variable S is usually referred to as shadowing and it captures the path loss deviation from its median value. For simplicity of the model, assume independence between the parameter γ and σ. The Gaussian distribution is completely defined by its first and second moments:

$$\gamma = \mu_\gamma + \sigma_\gamma * x_1$$
$$\sigma = \mu_\sigma + \sigma_\sigma * x_2 \qquad (6)$$

where x_1 and x_2 are iid zero mean, unit variance Gaussian random variables. Finally the complete statistical path loss model is defined as described in Ghassemzadeh and Tarokh (2002).

LOS/NLOS BS Identification: The shadowing effect can be reduced by data smoothening. For this, let Pi be the received mean path loss at i^{th} BS. The R_{LOSi} and R_{NLOSi} are the estimated propagation distances under LOS and NLOS environments respectively and written as:

$$\text{LOS: } R_{LOSi} = 10^{(pi-47)/10*n_{LOS}} \text{ (m)}$$
$$\text{NLOS: } R_{NLOSi} = 10^{(pi-50.5)/10*n_{NLOS}} \text{ (m)} \qquad (7)$$

The values R_{Ti} are the threshold values obtained by the LOS/NLOS decision boundary.

By using the TOA range measurement R_i, a testing is performed to discriminate LOS and NLOS conditions:

$$H_1 \text{ (LOS): } R_i \geq R_{Ti}$$
$$H_0 \text{ (NLOS): } R_i < R_{Ti} \qquad (8)$$

As the result of this testing, the weight factors are assigned by the following rules:

$$H_1 \text{ (LOS): } \alpha_i = |1 - |(R_i - R_{Ti}) / (R_{LOS} - R_{Ti})|| * 0.5$$
$$H_0 \text{ (NLOS): } \alpha_i = 1 - (|1 - |(R_i - R_{NLOS}) / (R_{Ti} - R_{NLOS})|| * 0.5) \qquad (9)$$

The weight factors from the three BSs describe the credibility of TOA range measurements. The algorithm can be summarized as non-linear unconstrained optimisation approach and is represented as:

$$(X_{\text{mobile station}}, Y_{\text{mobile station}}) = \arg\min \{F(X)\} \qquad (10)$$

and can be solved by MATLAB unconstrained nonlinear minimization function.

SIMULATION RESULTS

The performance of the location estimation algorithm is examined with the BSs – MS configuration, with true MS location (6, 5) and the coordinates of the BSs are BS1 (0, 0), BS2 (20, 0) and BS3 (10, 10). All the numerical quantities are expressed in meters. Assume one BS is an NLOS measurement and the other two are LOS BSs.

Figure 3 shows the output from GCC. The first curve shows the transmitted signal by the MS. The second curve shows the delayed signal received by the BS. The third signal shows the cross correlated output of first two signals, which gives the time delay of the signal received by BS. This is used for range measurement using TOA.

Figure 4 shows the effect of weight factors on ALE in the TOA algorithm in which NLOS/LOS case are simulated. It indicates that ALE remains constant, if equal weights are selected. When smaller weights are selected for the LOS BSs, the ALE is reduced. The accuracy improvement of location estimation is obtained when any two BSs are of LOS and smaller weights are used.

Figure 5 shows the estimated mean path loss and its variance of LOS and NLOS data as a function of T-R separation. By using the mean path loss and its variance, decision boundary that separates the path loss under LOS and NLOS condition can be derived with the help of Eq. (8). The values R_{Ti} are the threshold values obtained by the LOS/NLOS decision boundary shown in Fig. 6.

Based on MATLAB simulation the estimated position of the MS is (6.078, 5.09) whereas the true position of MS is (6, 5). It can be seen that for the error model considered, the proposed hybrid TOA/RSSI location algorithm performs better than other algorithms described in Chin-Der and Hao-Chun (2007). The results are due to the LOS/NLOS

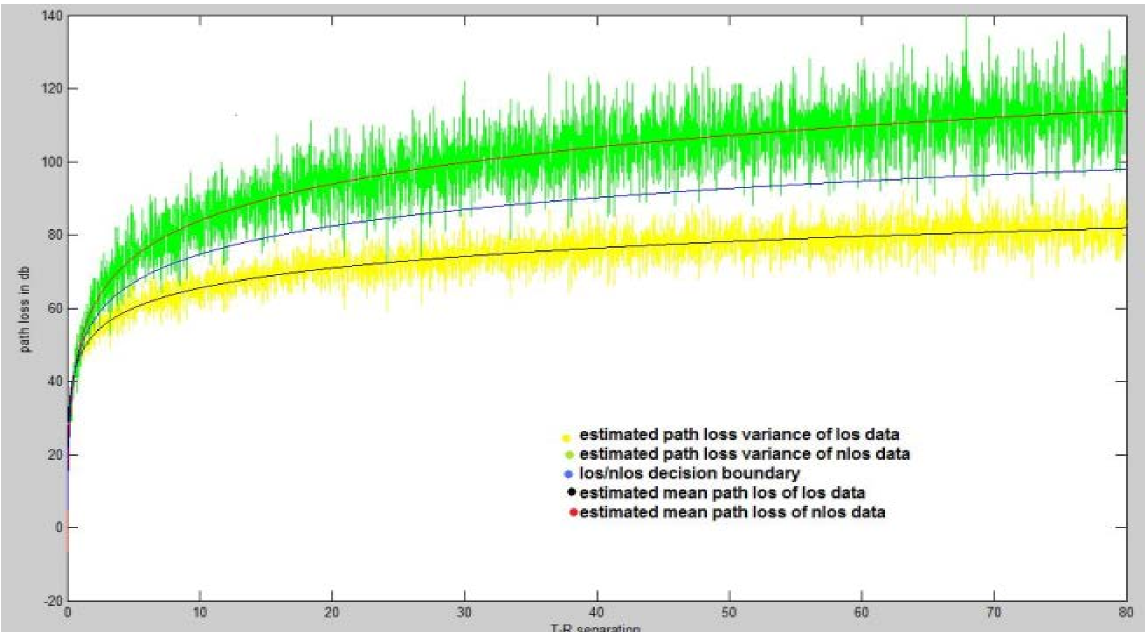

Fig. 5: Estimated mean path loss and its variance output

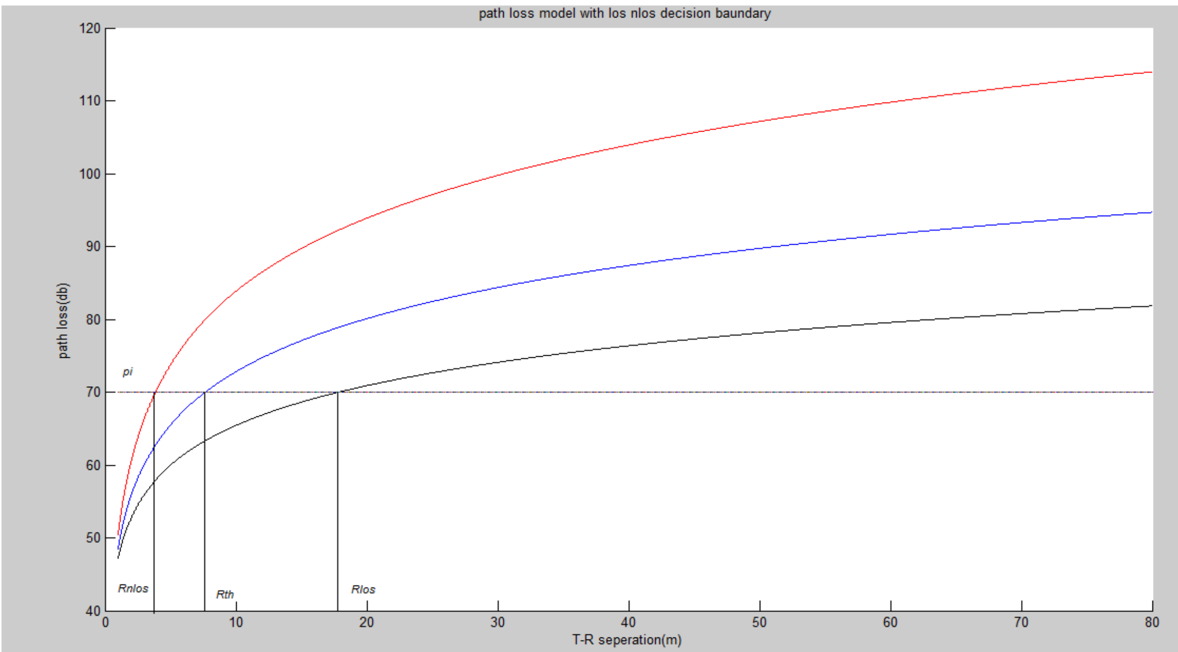

Fig. 6: PL distance mapping for LOS/NLOS identification

identification and the selection of weight factors which reduces the location error for the proposed algorithm.

The NLOS error not only depends on the environment and BSs-MS deployment but also on the performance of different location algorithms.

CONCLUSION

In this study, for accurate calculation of position of MS, a hybrid TOA/RSSI indoor wireless location technique using unconstrained optimization technique for UWB application has been proposed. This location algorithm uses BSs without the knowledge of LOS/NLOS conditions, assesses range measurements based on TOA using GCC. The NLOS effects are alleviated by an unconstrained nonlinear optimization technique which utilizes to process TOA and RSSI measurements, which are further given to BSs in the location system. The LOS/NLOS decision boundary is devised using path loss models and geometrical layout based on the TOA's. The integrity of the TOA measurements lies on the weight factors that are assigned based on LOS/NLOS identification while the objective function is cracked using an unconstrained nonlinear optimization technique. The solution is obtained by using MATLAB unconstrained nonlinear minimization function. Thus it can be conclude that this algorithm provides a pragmatic solution to accurate position location in an indoor environment while under grave NLOS conditions.

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