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Performance Evaluation of an Ultra Wideband Radiolocation System with Directional Beacon

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***Abstract* — In radiolocation, an ultra wideband (UWB) directional beacon provides several advantages such as enhanced range and link performance, reduced interference, and increased system capacity. Previous research analyzed the location error with a directional beacon in a Rayleigh channel model under the assumption of the existence of the line-of-sight (LOS) path and detection of the first multipath [1]. In this paper, we investigate the location error for a UWB system based on directional beacons in a UWB multipath environment. For simulation, we locate four rotating directional beacons at the corners of a 100 m x 100 m square and set the SNR=30 dB. Our results indicate that the mean location error is less than 1 cm under the existence of LOS paths for all the four beacons and 5.6 cm if one beacon does not have a LOS path.**

***Index Terms* — angle of arrival, directional beacon, line-of-sight, radiolocation, time difference of arrival, ultra wideband, sensor network.**

I. INTRODUCTION

Recently, ultra wideband (UWB) has been the focus of intense research and development [2]-[5]. A unique advantage of UWB is its dual capabilities of communications and radar. Radar capability offers several applications such as through-wall imaging, medical imaging, and automobile collision avoidance. The radar capability of UWB can be applied for position location of both mobile and static targets. In this paper, we consider a static environment such as wireless sensor networks or precision asset location.

The radar capability of UWB can find distances between nodes in a network. To find the relative position of nodes, many radiolocation methods try to find an exact or closed form solution [6]. For localization in NLOS (non line-of-sight) channel conditions, two main approaches are: 1) identifying the NLOS path and differentiating it from the LOS path with certain *a priori* information such as additional reference nodes [7], or 2) minimizing the location error using a geometrical or statistical approach [8],[9].

Angle of arrival (AOA), received signal strength indicator, time of arrival (TOA), and time difference of arrival (TDOA) can be utilized to find link distances between nodes [8]. However, due to the multipath fading and scattering near antennas, the delay based methods of TOA and TDOA are preferred in wireless networks such as CDMA. A TDOA based method for position location does not require synchronization between the transmitter and the receiver. In addition, there is a closed form solution for a TDOA based method [6] under AWGN.

Since UWB is a good candidate for position location, we investigate the performance of a UWB radiolocation system with directional beacons in a UWB multipath channel. The organization of this paper is as follows. Section II reviews a radiolocation scheme relevant to our work. Section III describes our proposed system model for UWB radiolocation. Section IV discusses simulation results, and Section V concludes the paper.

II. PRELIMINARIES

In this section, we review position location methods and present materials necessary to understand our UWB radiolocation system.

A. *Position Location with Directional Beacon*

Recently, the directional antenna concept has been widely investigated in wireless ad hoc networks at various network levels such as routing [10], medium access control [11], and positioning [1]. Positioning with directional antenna beams, or beacon location, and its geometrical analysis are reviewed in [12].

We briefly review the beacon location approach presented in [1], which is the basis for the proposed research. In [1], directional beacons locate the target assuming the existence of the LOS path. The location accuracy is dependent on the beam width as well as the multipath components due to reflections. Three multipath components are considered for each beacon (or reference) node in [1], and the beam width is assumed ideal for directional beacons.

Figure 1 shows the geometry considering a LOS radio-path from the reference node to the sensor node. Each beacon at a reference node rotates in the same direction (viz. clockwise) with a constant angular velocity of ω, and the difference in angle for two adjacent beacons is ϕ (which is 180 degrees in Figure 1) at any moment. Suppose that the pulses are received at sensor node SN at t_1, t_2, and t_3 from RN-1, RN-2, and RN-3, respectively. Let α and β be as follows.

$$\alpha = \phi - \omega\tau_1$$
$$\beta = \phi - \omega\tau_2 \qquad (1)$$

where $\tau_1 = t_2 - t_1$, $\tau_2 = t_3 - t_2$. Using trigonometry, we obtain the equations for the location of sensor node SN as follows [1].

$$\gamma = \arctan \{[\cos(\beta)\text{-}S\sin(\alpha)]/[S\cos(\alpha)\text{-}\sin(\beta)]\}$$
$$Y = L\sin(\alpha+\gamma)/\sin(\alpha) \qquad (2)$$

where

$$S = L\sin(\beta)/M\sin(\alpha). \qquad (3)$$

Finally, the location of sensor node SN is obtained as

$$X_p = Y\cos(\gamma)$$
$$Y_p = M\text{-}Y\sin(\gamma) \qquad (4)$$

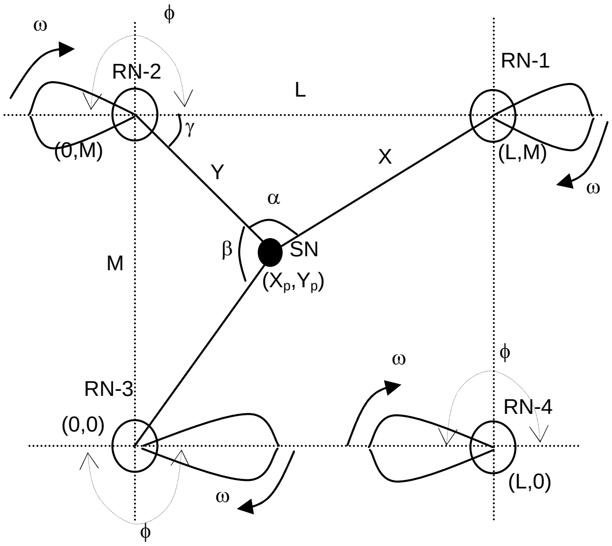


Figure 1: Rotational beacons and their operations [1].

Similarly, three more location estimates can be obtained from the measured time differences from any three reference nodes. Thus, four combinations of three reference nodes give four estimates of the location, and the best estimate is obtained using a heuristic similar to pattern matching.

Three multipath components (due to the reflection) are assumed in [1], and the SN sequentially receives signals from RN-1, the RN-2, and so on. With three multipath components from each reference node, the SN receives a total of nine multipath components if one set of three reference nodes is used for the localization. The TOA due to the differences in radio-paths is ignored, since beacons rotate very slowly. Hereafter, we call this method as PATMAT for convenience. For further details, refer to [1].

B. UWB Pulses and Multipath Channel Model

Gaussian monopulses are widely used for UWB systems due to the desirable shape of the spectrum and the existence of a simple closed form expression [13]. The received signal is modeled as the derivative of the transmitted signal, which is Gaussian doublet in this case. We adopt a UWB pulse with 250 Kbps data rate and 10 dB bandwidth 1.7 GHz. The PRI (Pulse Repetition Interval) is 4 μsec according to the data rate of 250 kbps. Pulses are transmitted at different angles as the beam rotates with a constant angular velocity. Thus, if we assume an angular resolution of α degree, 360/α pulse trains are transmitted for each rotation. For example, if the angular resolution of 3°, 120 pulse trains are transmitted.

Since the PRI is on the order of μsec, inter-symbol interference does not occur in the UWB channel. We employ the channel model proposed by Cassioli et al. [14]. Figure 2 displays the average power delay profile of Cassioli's model. Time is measured relative to the first arriving multipath, and the amplitude of each vertical line represents the energy gain of each 2 ns delay bin. The RMS (Root Mean Square) delay spread of this channel model is 38.7 nsec [15].

The multipath components, including the first multipath, are chosen randomly from the generated channel profile for our simulation. We do not consider interference from other systems. So the remaining major sources of error, which impact the radiolocation accuracy, are AWGN and NLOS multipaths.

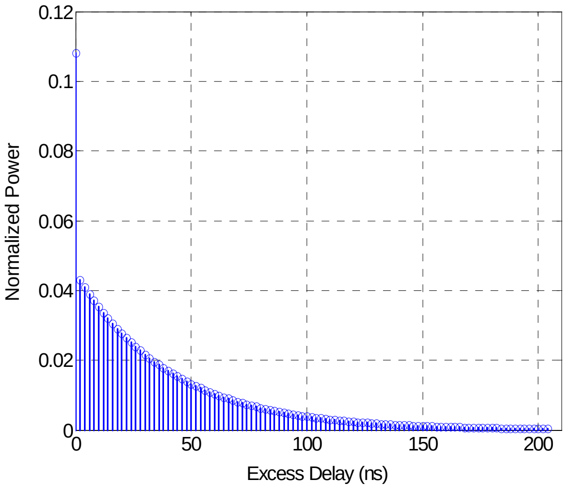


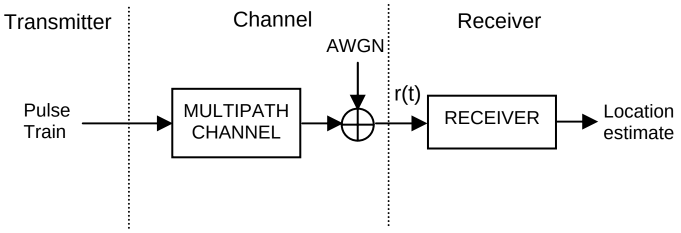
Figure 2: Average power delay profile of the Cassioli channel.

III. UWB Radiolocation System Model

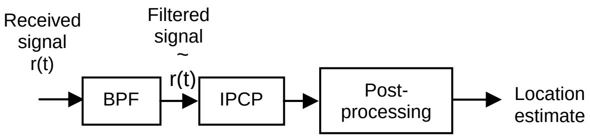
We assume a UWB radiolocation system with four reference nodes and a stationary sensor node inside the perimeter of the four reference nodes as shown in Figure 1. Each reference node transmits a directional beam, which rotates at a slow and constant angular velocity, to the sensor. The sensor node knows the instantaneous angle of each reference node as each reference beacon sweeps over the sensor node. The angle information is utilized to compute the TDOA.

We assume that the reference nodes are perfectly synchronized through GPS (Global Positioning System) or a direct wire connection. The directional beams are achieved through beamforming with smart antennas or physical rotation of a directional antenna. Note that synchronization between a sensor node and a reference node is unnecessary for our system, since we are interested in absolute arrival times of pulses to compute AOA.

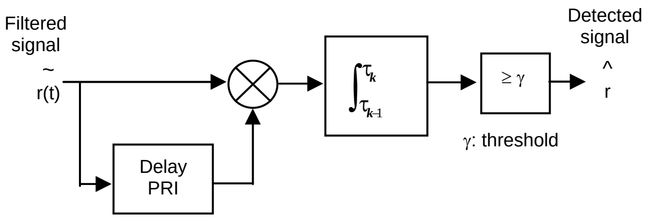
Figure 3 (a) shows the proposed UWB radiolocation system, in which the transmitter is a reference node and the receiver is the sensor node. Figure 3 (b) shows the receiver model. The BPF is a bandpass filter for the received signal. The interleaved periodic correlation processing (IPCP) in Figure 3 (c) performs correlation between the received signal and the delayed version of previous signal. IPCP is adopted for our system, since it does not require synchronization [16].



(a) Transmitter and channel model



(b) Receiver model



(c) Interleaved periodic correlation processing (IPCP) model

Figure 3: Block diagrams of the proposed UWB radiolocation system.

IV. SIMULATION RESULTS

To estimate the performance, we simulated the proposed UWB radiolocation system. We generated a UWB beacon as train of pulses, which were transmitted at with angular resolution of 1°. The remaining parameters for our simulation are as follows:

- Geometry for the sensor field: 100 m × 100 m
- Number of multipath components: 3
- Integration time (τ): 2 nsec
- Number of reference nodes: 4

Gaussian monopulses with bandwidth of 1.7 GHz were used for our simulation. Multipath components were generated from the Cassioli channel model. Since we are interested in several multipaths including the LOS direct paths, we generated the Cassioli channel profile and then extracted several random profiles for specific excess delays. The simulation results were obtained for two cases through 20 independent experiments. For the first case *LOS4*, there exists a LOS path from all four reference nodes to the sensor node. For the second case *NLOS1*, one reference node does not have a LOS path to the sensor node, i.e., the reference node has only NLOS paths.

Figure 4 shows the mean location error under the default simulation parameters. Note that the location error is in logarithmic scale. When there are four LOS paths (LOS4), a location error of less than 2 cm is achieved for the entire range of the SNR from 25 dB to 30 dB. Further, the location error is more or less independent of the SNR. However, when one reference node does not have the LOS path (NLOS1), the mean location error decreases rapidly as the SNR increases. For instance, when the SNR increases from 25 dB to 30 dB, the error is reduced from 5 m to 5 cm. It is interesting to note that the error drops suddenly from SNR =29 dB to 30 dB for NLOS1.

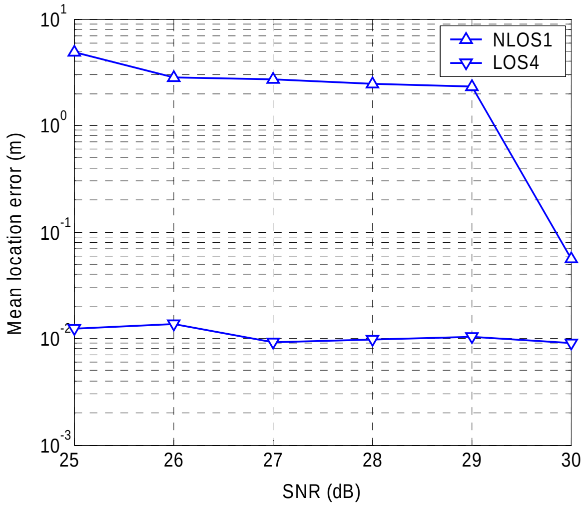


Figure 4: Mean location error versus SNR.

Table I shows statistics of the 20 experiments for the two cases under SNR = 30 dB. The mean location error is 0.9 cm with the standard deviation of 0.4 cm for the former case (LOS4), while the mean location error is 5.6 cm with the standard deviation of 13.3 cm for the latter case (NLOS1). This indicates that high accuracy is ensured for the entire SNR range only when the LOS exists for all the four reference nodes. When a reference node does not have the LOS path, it needs to increase the SNR above the threshold value for good accuracy. The NLOS problem can be mitigated through the increase of reference nodes, since it is likely to increase the number of LOS paths.

TABLE I: STATISTICS OF MEAN LOCATION ERROR

Parameters	SNR (30 dB)	
Statistics	Mean Error (cm)	Std Deviation (cm)
LOS 4	0.9	0.4
NLOS 1	5.6	13.3

V. CONCLUSION

We proposed a UWB radiolocation system with directional beacons and investigated the location error of the system through simulation. High accuracy of less than 2 cm is achieved if all four reference nodes have LOS paths. However, even if one reference node does not have a LOS path, the error becomes large for SNR below a certain value. So it is a good approach to ensure LOS paths by increasing the number of reference nodes. The positioning of reference nodes and overall geometry for sensor fields can be a suggested future work for enhancing location accuracy in a cluttered environment.

Our investigation shows the feasibility of a UWB radiolocation using directional beacons at reference nodes. Moving most of the radiolocation functionality from the sensor nodes to reference nodes is more cost effective. Further, it does not require synchronization between the reference nodes and sensor nodes, which simplifies the system design.

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