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TDOA Computation Using Multicarrier Modulation For Sensor Networks With Efficient Bandwidth

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ABSTRACT:

Locating accurate positions of the nodes is normally required in Sensor Networks which are attempting to locate and track an emitter or sources of signals. GPS is normally used as it provides high accuracy position measurement, but it has its own limitations. In this paper, we propose a Bandwidth Efficient TDOA (Time difference of arrival) Computation using OFDM for Sensor Networks. Simulation results indicate the performance of the algorithm in terms of Signal-to-Noise (SNR) ratio and Bandwidth utilization considering Centralised and De-Centralised methods.

Keywords: ***Orthogonal frequency division multiplexing, Time difference of arrival, sensor networks, GPS***

I. INTRODUCTION

Accurate position measurement is important for many source localization and navigation problems. Wireless sensor networks require determining the position of the source in a wireless transmission. In the navigation problem, the premise is to use existing wireless infrastructure [15] such as radio and television towers at known locations, to determine the position of a mobile receiver. Although the global positioning system (GPS) usually provides worldwide high-accuracy position measurements, it requires lines of sight to multiple satellites. Hence, it is ill-suited for use in indoors, underground, or in urban canyons. Moreover, in the presence of radio frequency interference or jamming, GPS may be unavailable [14]. That's why, alternative methods of navigation and positioning are of interest, either as a backup or for use in areas unreachable by satellites.

The principle behind GPS working is the measurement of distance (or "range") between the satellites and the receiver. The satellites tell us exactly where they are in their orbits by broadcasting this data .The receivers uses this data to compute their positions. It works something like this: If we know our exact distance from a satellite in space, we know we are somewhere on the surface of an imaginary sphere with a radius equal to the distance to the satellite radius. If we know our exact distance from two satellites, we know that we are located somewhere on the line where the two spheres intersect. And, if we take a third and a fourth measurement from two more satellites, we can find our location. The GPS receiver processes the satellite range measurements and produces its position.

For both the source localization and the navigation problem, the intent is to determine the relative position of the transmitter and the receiver. Measurements that can be taken to aid this process include

1. Angle of Arrival (AOA)
2. Received signal strength (RSS)
3. Time of arrival (TOA)
4. Time difference of arrival (TDOA)

In either the source localization or navigation problem, one common approach relies on time difference of arrival (TDOA) measurements to multiple nodes. In this paper, we investigate a bandwidth efficient method of TDOA computation when the signals of opportunity use UWB multicarrier modulation. By exploiting the structure of the multicarrier transmission, much less information needs to be exchanged between nodes compared to the standard cross correlation approach. For a given level of performance, the proposed approach requires two to three times less bandwidth.

II. ANGLE OF ARRIVAL (AOA)

When using the AOA [1] technique, a mobile receiver estimates the signal reception angles for two or more sources with known locations. It does this by comparing either the carrier-phase or signal amplitude across multiple antennas. From these calculations, the target receiver's position is triangulated by the intersection of the angle line from each signal source. Fig 1 illustrates the improvement in

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accuracy when using more than two sources. This passive navigation method is easily implemented. However, AOA calculations are very susceptible to range. As the distance from the source increases, the position accuracy decreases.

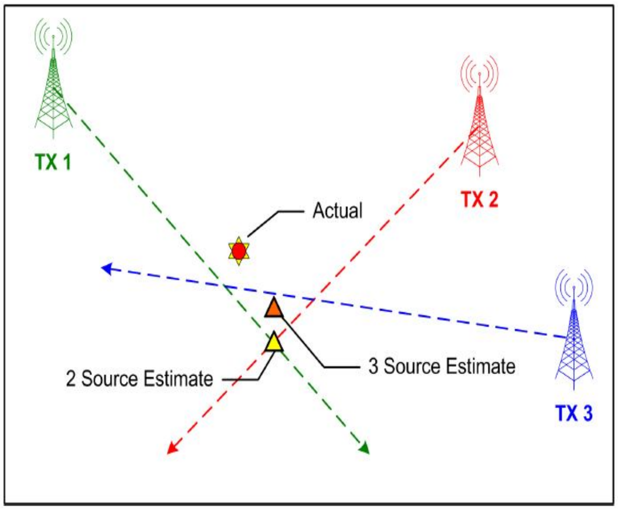

Fig 1: AOA Technique.

III. RECEIVED SIGNAL STRENGTH

This method of radiolocation uses a known mathematical model that depicts the path loss attenuation over distance between a mobile receiver and a transmitter. By detecting multiple transmitters, the mobile receiver's location can be calculated accurately. However, this measurement of signal strength is susceptible to error mainly due to multipath interferences.

RSS is frequently used, but it generally requires assuming that the transmitted power and the path loss exponent are known or are included as additional parameters to be estimated, that there is no multipath or shadowing, and that the transmitter antennas is isotropic - assumptions which are generally not valid.

IV. TIME OF ARRIVAL (TOA)

In TOA calculations, the distance between a mobile receiver and a transmitter is measured by finding the one-way propagation time between the two. This measurement then provides a geometric circle, centred on the transmitter, on which the mobile receiver must lie. Similar to signal strength measurements, receiving signals from more than one transmitter can resolve ambiguities because the mobile receiver will lie on the intersection of the circles. Fig 2 illustrates this intersection.

TOA calculations require all transmitters be time synchronized. If all of the transmitters are synchronized, then synchronizing the receiver is unnecessary because the receiver clock error is constant for all transmitters. This clock error can then be accounted for with additional calculations, thus eliminating the receiver clock error altogether from the TOA measurements.

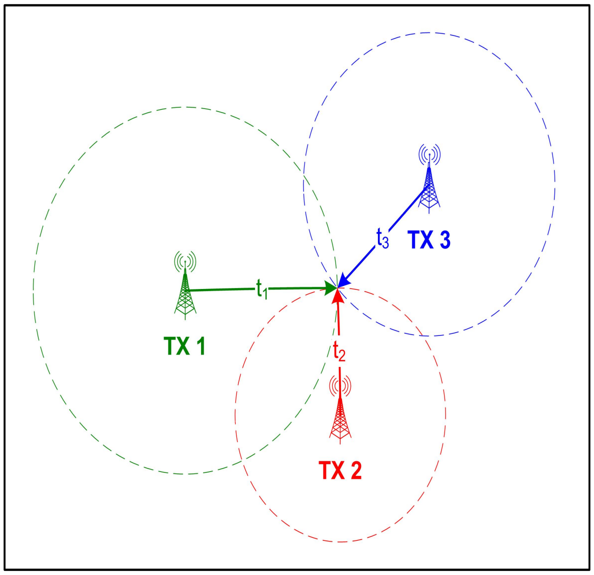

Fig 2: TOA Technique. Position is found by determining the one-way propagation time between multiple transmitters and the mobile receiver.

V. TIME DIFFERENCE OF ARRIVAL (TDOA)

These systems focus on measuring the difference in arrival times of two transmitted signals by a single receiver, or by differencing the arrival time of a single signal at two separate receivers. One of the two receivers, known as the target or mobile receiver, has an unknown location while the other receiver, referred to as the reference receiver, has a known location. These two receivers have a data link between them, where the reference receiver shares signal reception information with the target receiver. The difference in the reception time between the two receivers allows for a position calculation.

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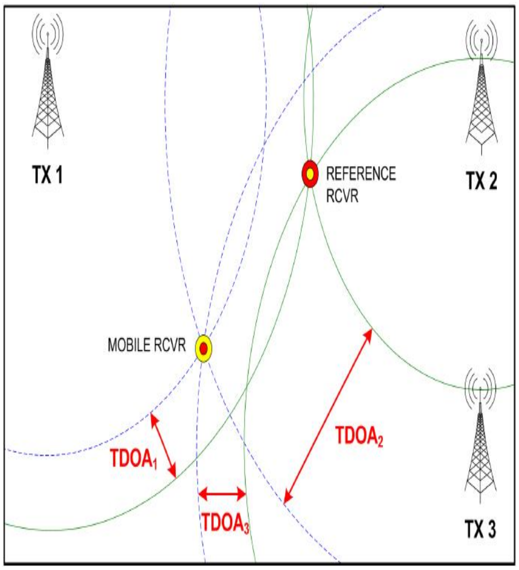

Fig 3: TDOA Technique.

Usually only one transmitter is available and hence multiple sources or receivers must cooperate by sharing data. One difficulty that arises from this is that the sharing of data requires significant bandwidth (as opposed to RSS or AOA-based methods). Specifically, TDOA measurements are often determined from the generalized cross correlation of the two received signals which requires that one of the two nodes involved in each TDOA computation retransmit a long portion of the signal it receives to the other node involved in the computation. However, this may require large amount of bandwidth and power, which are limited resources for mobile, wireless devices. To overcome the requirement of large amount of bandwidth and power in TDOA-based method we propose the partially decentralized method of TDOA computation.

On comparison of the different source localization techniques, we find in some applications, TDOA is an attractive alternative. The position estimate can be obtained by first estimating the TDOAs and then using the TDOAs to estimate the position. Thus, in this paper, we focus on TDOA estimation, rather than direct position estimation.

The performance of a wireless sensor network generally depends on the following factors: energy efficiency, latency, accuracy, fault tolerance, scalability, Synchronization and localization, and throughput.Wireless sensor networks (WSNs) have found extensive applications in several domains such as target detection, localization and tracking, environmental monitoring, and health monitoring. In all these applications, sensors usually transmit data to a sink node via a single or multi hop path. The connectivity of each node to its next hop neighbor along the path determines whether or not the data is received successfully at the sink. Hence, the connectivity of the network plays a major role in sensor network applications. In addition, sensors which cannot communicate with any other sensor get isolated and hence their data can never be delivered to the sink. Hence, isolated nodes are an undesirable characteristic of a sensor network.

VI. SYSTEM MODEL

The basic OFDM system is as shown in fig 4.The idea is to break up a frequency-selective multipath channel into a bank of flat narrowband channels. This can be accomplished by parsing the source data into N parallel lower rate data streams, and modulating them with linearly spaced carrier frequencies. Equivalently, we can apply an inverse fast Fourier transform (FFT) to each successive block of N data samples. Then equalization can be done after a demodulating FFT at the receiver, simply by inverting the channel in the frequency domain

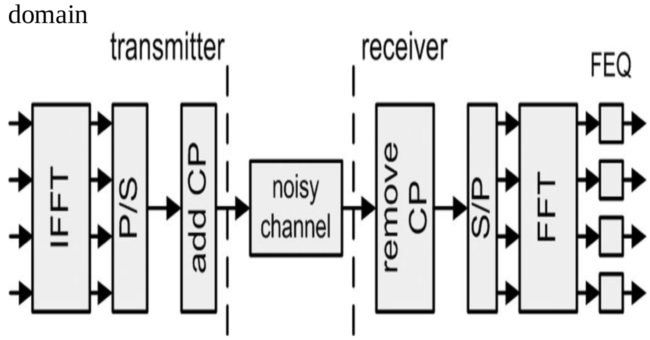

Fig 4: Block diagram of a multicarrier transmitter and receiver. (I)FFT: (inverse) fast Fourier transform, CP: cyclic prefix, P/S: parallel-to-serial, S/P: serial to parallel, FEQ: frequency-domain equalizer

VII. TDOA COMPUTATION

Centralized Computation

The traditional method [9] of computing TDOAs involves a correlation of the raw data received at the primary and reference receivers. The reference receiver retransmits a copy of 'k' samples it receives $Y_{ref}(k)$, to the primary receiver. Then the latter performs a correlation:

$$R_y(d) = \sum_{k=1}^{k} Y_{ref}(k) Y_{pri}(k+d) \qquad \text{---- (1)}$$

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The primary must compute for all anticipated valid ranges of the block arrival time difference say 2D blocks or $-D \leq d \leq +D$. Then the TDOA can be computed a

$$\delta = \arg \{ max\, R\{R_y(d)\}\} \quad -D \leq d \leq +D \qquad \text{----------- (2)}$$

$$TDOA = \delta Ts$$

Where R{.} is the real operator and 'Ts' is the sample period. Throughout the remainder of the paper, we refer to this as the traditional, centralized approach [9], since all of the raw data must be retransmitted to a central location for processing.

Proposed Decentralized Computation

The proposed TDOA computation is a two-step process:

Step1: (block boundaries): The reference uses the CP [11] to locate the block boundaries within the signal that it receives. Simultaneously and independently, the primary performs the same task on its received signal.

Step2: (feature extraction): The reference and the primary each compute a single, scalar statistical feature from each block. The reference transmits the feature values and boundary times of the associated blocks to the primary, which then correlates the sets of feature values in order to line them up.

VIII. SIMULATIONS

This section explains the performance analysis using simulations. The transmitter uses multicarrier modulation with an FFT [1] size of N=64, a cyclic prefix (CP) length of v=16, and a block size of M=80. Simulated probability of synchronization error versus SNR, in the presence of multipath is shown in Fig 4. The effect of multipath is as the channels each had a Ricean LOS path and a Rayleigh fading path.

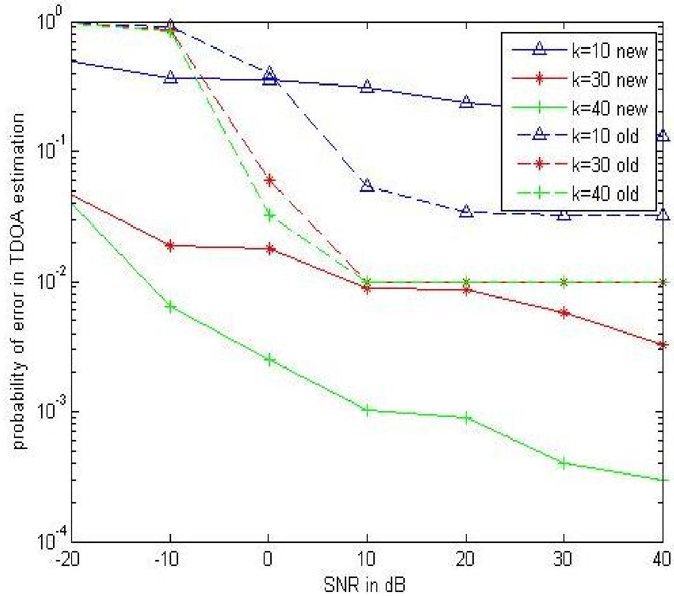

Fig 5: Simulated probability of synchronization error versus SNR, in the presence of multipath. The channels each had a Ricean LOS path and a Rayleigh fading path.

In Fig. 5 the presence of multipath is simulated with a ricean fading path and three different Rayleigh paths, the probability of error versus SNR [1]. We showed the fading paths with different channels. In the legends "new" is the proposed approach.

In Figures 5 and 6 by comparing the centralized approach with proposed approach we can say that the probability of error is decreasing with the number samples being increased. Figure 7 shows the probability of error versus correlation SNR for D=10 (no. of blocks). Every magnitude of increase of block size corresponds to increase in the magnitude of probability of error.

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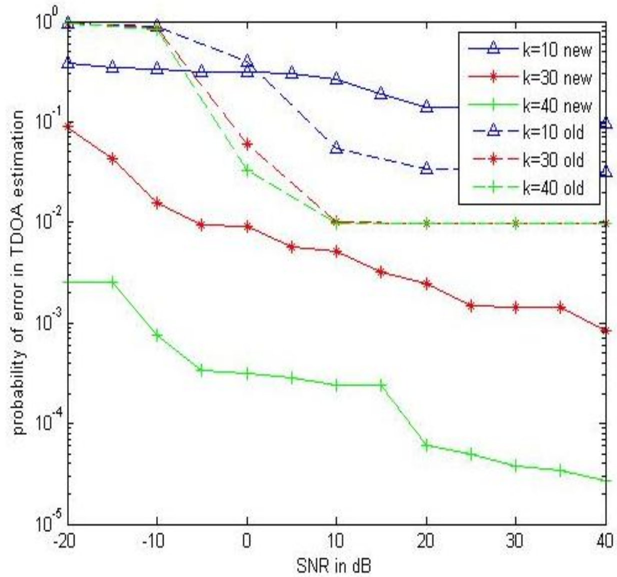

Fig 6: Simulated probability of synchronization error versus SNR, in the presence of multipath. The channels each had a Ricean LOS path and three Rayleigh-fading paths.

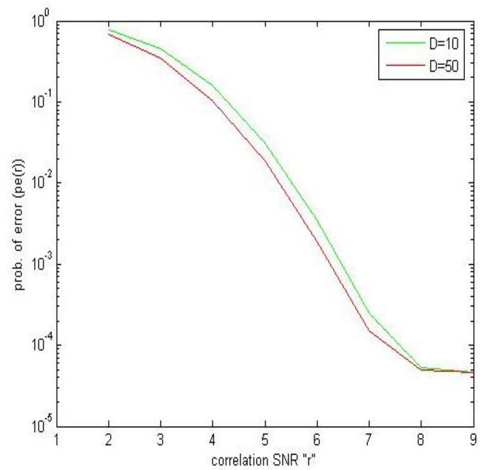

Fig 7: Probability of error in the TDOA estimate as a function of the "correlation SNR".

IX. CONCLUSION

In this paper we discussed different source localization techniques namely AOA, RSS, TOA and TDOA and showed that TDOA is best suited for source localization in UWB context aware applications and wireless sensor networks. The requirement of large amount of bandwidth and power by TDOA-based method of source localization is overcome by the proposed partially decentralized approach of TDOA computation. We analytically evaluated the performance of the proposed, partially decentralized approach and compared it to that of the standard centralized approach. For a given level of performance, the proposed partially decentralized approach requires two to three times less bandwidth and hence is bandwidth efficient.

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