International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-3, Issue-1, March 2014

Asset Localization in Industrial Wireless Sensor Networks based on Ultra Wideband

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***Abstract:** Real-time location systems (RTLS) help ensure that assets are in the right place at the right time. There are numerous possible applications afforded by tagging assets such as improving routing and multiple access control protocols in wireless sensors network which prolong its operational life time. Ultra Wideband (UWB) wireless technology offers greater resistance to multipath fading, interference, and potentially lowers power consumption. Therefore UWB technology inherently enables the accurate localization of assets. In this paper, localization method based on a passive Time difference of Arrival (TDOA) scheme using IEEE802.15.4a "industrial environment" channel model is implemented using Matlab and tested. A new proposed waveform based on Gaussian pulse is used for localization, which decreases the interference between the UWB and other signals, and decreases the probability of error (prb). The proposed localization scheme decreases the error between real asset location and estimated position at low level of signal to noise ratio (E/No).*

***Keywords:** UWB, Localization, IEEE802.15.4a*

I. INTRODUCTION

Ability to locate assets will be improving not only emerging location-based services, but also mobile advertising, safety, and security applications [1].

The Global Positioning System (GPS) requires communication with at least three GPS satellites, and offers location accuracy of several meters. Its accuracy can degrade significantly in indoor scenarios, so it is used mainly for outdoor location-based applications. The high power consumption by terminals during the localized process beside the accuracy gives the reasons to exclude GPS and use other technology [2].

This problem is solved by using UWB which became popular after the Federal Communications Commission (FCC) in the USA allowed the unlicensed use of UWB devices in February 2002 subject to emission constraints. UWB can coexist with other wireless devices, because its unlicensed operation and low power transmission, and it's low-cost, it a good candidate for short to medium-range wireless systems such as WSNs according to its low-power transceiver circuitry [3]. According to the FCC rulings, UWB is defined as any transmission scheme that occupies a fractional band width greater than 0.2 or a signal bandwidth of more than 500 MHz The fractional bandwidth is defined as B/F_c, where $B = F_H - F_L$ represents the −10 dB bandwidth and $F_c = (F_H + F_L)/2$ denotes the center frequency.

Here F_H and F_L are the upper frequency and the lower frequency, respectively, measured at −10 dB below the peak emission point. Based on [4], UWB systems with $F_c > 2.5$ GHz need to have a −10 dB bandwidth of at least 500 MHz, whereas UWB systems with $Fc < 2.5$ GHz need to have a fractional bandwidth of at least 0.2. The FCC has mandated that UWB radio transmission can legally operate in the range 3.1 to 10.6 GHz. A signal that perfectly fills this available bandwidth gives a maximum transmission power of 0.55 mW (-2.6 dBm) when integration over the FCC mask is performed. The spectrum of the transmitted signal will depend on the pulse shape of the signal and how the pulses are placed in the time domain. The most common pulse shapes are different variations of Gaussian pulses [5].

II. POSITION ESTIMATION TECHNIQUES

The position of a node in wireless system is determined through the collection of location information from the radio signals exchanged between the target and a number of reference nodes. Depending on the positioning technique, the angle of arrival (AOA), the received signal strength (RSS), or time delay information can be used to determine the location of a node. The RSS and time-based approaches estimate the distance between nodes by measuring the energy and the travel time of the received signal, respectively, while The AOA technique measures the angles between a given node and a number of reference nodes to estimate the location [6]. The AOA approach use an antenna array, this array must be long enough to damping the variation in the estimation angle. Use of antenna arrays increases the system cost, annulling the main advantage of a UWB radio equipped with low-cost transceivers. So AOA approach is not suitable to UWB positioning [7].

The characteristics of the channel must be known, to determine the distance from RSS measurements. Therefore, RSS-based positioning algorithms are very sensitive to the estimation of those parameters, and the unique characteristic of a UWB signal, namely the very large bandwidth, is not exploited to increase the best achievable accuracy [7].

The increasing in the effective signal bandwidth will be improved the accuracy in time based approach. Since UWB signals have very large bandwidths, this property allows increasing in the accuracy of target position using time-based techniques via UWB radios. So the proposed scheme depends on time-based approach [7].

III. PROPOSED SCHEME

The proposed scheme is a passive localization scheme. Target transmits its signal to Reference nodes contains information about it. Reference nodes have synchronization only between each other.

Revised Manuscript Received on 30 March 2014.
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The interest area is dividing into regions. Each region has five reference nodes, one of them is the master node propagate the synchronize message. The time of the message from the target arrives to reference nodes passes to the master reference node. The position of the moving target (X_t, Y_t, Z_t) in this region determine by using time difference of arrival (TDOA) between the reference nodes. The estimation model in [8] is modulated to be suitable in three dimensions estimation.

IV. SIMULATION AND RESULTS

The proposed localization scheme is simulated by initializing WSN based on UWB. Nodes in the network have the ability to transmit and receive signals. Simulation system consists of three parts transmitter, receiver, and channel model. Then time parameters are extracted to calculate the position of the target.

The transmitter uses pulse position modulation (PPM) with time hopping (TH) to allow multiple accesses. Transmission process consists of four steps which are repetition coder, transmission coder, PPM modulator, and pulse shaper. The repetition coder repeats each input bit Ns times to produce binary sequence a at a rate of Rcb=Ns*Rb=1/Ts where Rb equal the input data rate and Ts is the frame time. The transmission coder applies integer value C into the previously generated sequence that produces a new code. This code introduces a TH shift on the generated signal. The PPM modulator produces a series of Dirac pulses δ (t) at the rate Rp = 1/Ts. The last process is the shaping of the generated pulses. This is done in the Pulse Shaper which has an impulse response p (t). The final expression for a PPM TH-UWB signal is shown in equation 1where Tc is the chip time, and ε is the PPM shift [9].

$$S(t) = \sum_{-\infty}^{\infty} P(t - jT_s + C_j T_c + a_j \varepsilon) \qquad (1)$$

IEEE 802.15.4a channel model is used in the simulation to achieve realistic results as possible. The model provides parameters for different environments inside the frequency range from 2 to 10 GHz. The selected industrial environment is modelled by larger factory halls, filled with a large number of metallic reflectors [10]. This structure lead to high multipath.The model is based on the Saleh and Valenzuela formalism. A single pulse arrives at the receiver in multipath components which grouped in clusters. The channel impulse response is expressed in equation 2. Where X is a log-normal random variable representing the amplitude gain of the channel, N is the number of observed clusters, K (n) is the number of multipath contributions received within the n-th cluster, αnk is the coefficient of the k-th multipath contribution of the n-th cluster { αnk,=pnkβnk, where pnk is ±1 with equal probability and βnk is the log-normal distributed channel coefficient of multipath contribution k belonging to cluster n}, Tn is the time of arrival of the n-th cluster and τnk is the delay of the k-th multipath contribution within the n-th cluster [9,11].

$$h(t) = X \sum_{n=1}^{N} \sum_{k=1}^{k(n)} \alpha_{nk} \delta(t - T_n - \tau_{nk}) \qquad (2)$$

The receiver is a RAKE receiver that is using to capture a significant amount of energy found in the multipath components. Especially the selective receiver (SRAKE) with five branches is used in this simulation. It gives a satisfactory signal quality while not exceeding the complexity of the sensor node [11].

Impulse Radio UWB (IR-UWB) transmission depends on using a certain very narrow pulse. The power spectral density (PSD) of the transmitted pulse must meet the emission mask of the FCC mask to prevent interference with other application. Second the pulse doesn't contain DC value to avoid degradation in antenna characteristics. In fact, of the popular pulses like Gaussian, Hamming, and Raised Cosine don't meet the FCC emission mask in the pure form. So in this paper a new pulse is developed base on Gaussian pulse to satisfy the requirement of UWB transmission.

The spectrum shape of the Gaussian pulse can be modified by pulse width variation, pulse differentiation, a combination of different derivatives, and filter. Using filter increase the cost in fabrication the sensor node beside the delay in transmission process. The algorithm in this paper depend on a random combination between the first five derivatives of the Gaussian pulse at certain values of the pulse shaping factor, then using least square error to meet the emission mask of the FCC. Equation 3 shows the derivative of the produced signal, where t represents the time and α represents the shaping factor of the pulse. Figure 1 and figure 2 show the produced signal and its derivative respectively in time domain, and there is no a DC component in the two signals. Figure 3 shows the PSD of the desired signal using equation 3 with α=0.2 ns and pulse repetition frequency equal 9 ns. Figure 3 shows the proposed pulse meets the FCC emissions mask, and the maximum PSD equal -41.79dBm/MHz (FCC boundary equal -41.3dBm/MHz) happens at frequency equal 6.1GHz. This values meet the environmental parameters as the central frequency equal 6GHz. Figure 4 shows the probability of error (prb) at different values of E/No for different kind of pulses. The probability of error decreased when used the proposed waveform compared with the fist fifth derivative of Gaussian pulse.

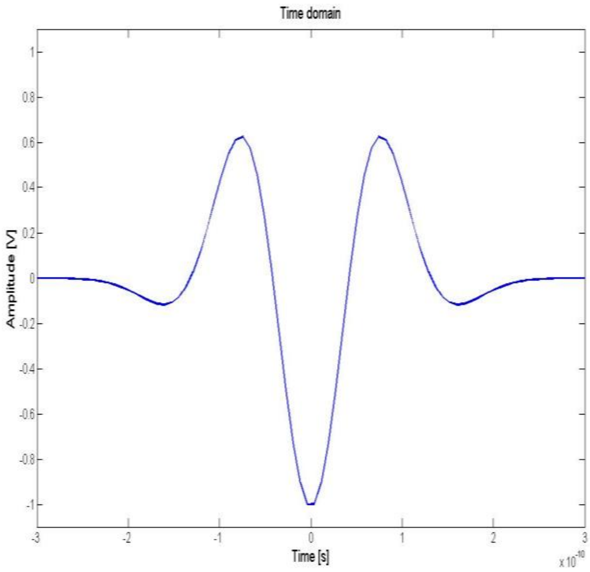

Figure1.waveform of the produced signal in time

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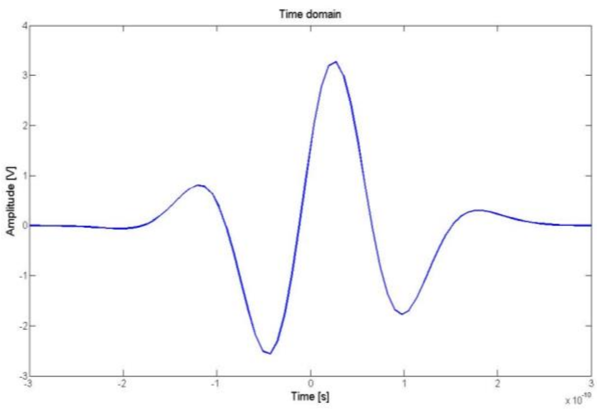

Figure2.waveform of the derivative produced signal in time domain

$$W=\left(\frac{\Pi}{\alpha^{2}}e^{\left[\frac{-2\Pi t^{2}}{\alpha^{2}}\right]}\right)*\left(\begin{array}{l}[-0.03t-1]+\left[\frac{0.466\Pi t^{2}-0.384\Pi t+75.7\Pi}{\alpha^{2}}\right]\\+\left[\frac{0.512\Pi^{2}t^{3}-604.8\Pi^{2}t^{2}+2563.2\Pi t}{\alpha^{4}}\right]+\\\left[\frac{403.3\Pi^{3}t^{4}\alpha^{2}-6835\Pi^{2}t^{3}\alpha^{2}+2734.1\Pi^{3}t^{5}}{\alpha^{8}}\right]\end{array}\right) \quad (3)$$

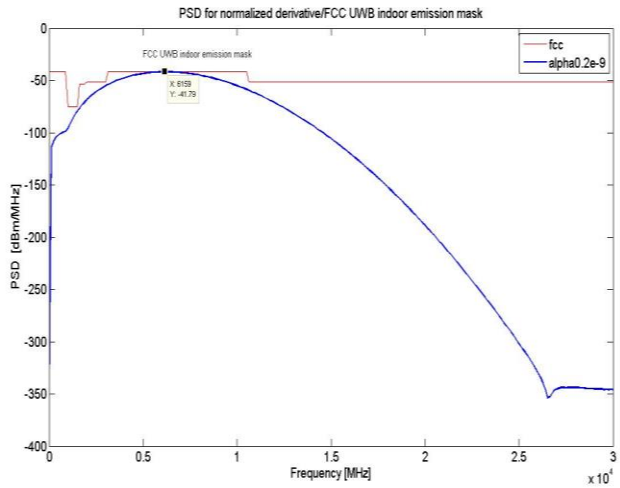

Figure3. The PSD waveform of the proposed signal

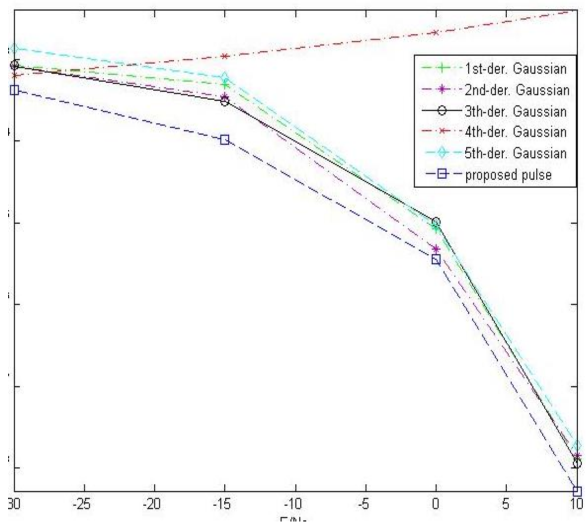

Figure4. The prb versus E/No for different kind of pulses

The localization of the moving target starts by determines the Z position of the reference nodes. Table 1 shows the average error for different sets of reference nodes at different locations of the target. From table 1, set number 5 produces the minimum average error. So this set of reference nodes will be used to locate the target in different locations.

Table 1: average error of different target location at different sets of reference nodes

Sets	Location of the reference nodes	Average error
Set1	[0 0 3;4 4 4;-4 4 5;-4 -4 6;4 -4 7]	2.57685cm
Set2	[0 0 3;4 4 4;-4 4 4;-4 -4 4;4 -4 4]	2.92507cm
Set3	[0 0 4;4 4 3;-4 4 3;-4 -4 3;4 -4 3]	2.73412cm
Set4	[0 0 3;4 4 4;-4 4 3;-4 -4 4;4 -4 3]	2.43605cm
Set5	[0 0 2;4 4 4;-4 4 3;-4 -4 3;4 -4 4]	1.45765cm
Set6	[0 0 2;4 4 4;-4 4 2;-4 -4 3;4 -4 2]	1.62607cm

Figure 5 shows the localization of the target in different places .The simulation was done at (E/No) equal zero dB at the receiver and sampling frequency at Nyquist rate 22 GHz. The error range between the real and estimated position of the target is 0.17 cm to 3.1 cm. In some methods as in [5] the localization of the target in the corner places is more difficult to estimate and leads to high errors. The proposed method overcomes this problem as show in figure 5.

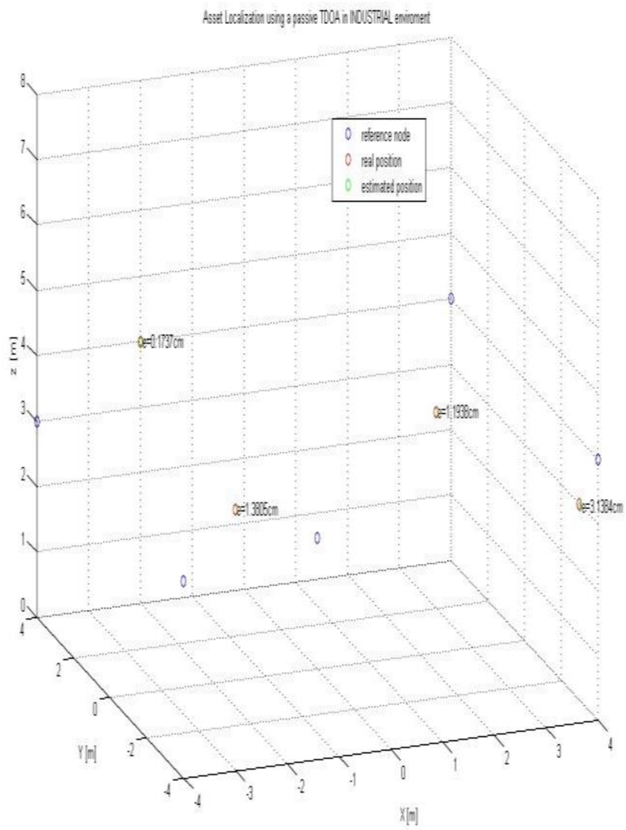

Figure5. Asset localization in different location

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Figure 6 shows the error (minimum, average, and maximum) between the real and estimated position of the target in different location at different levels of E/No at Nyquist.

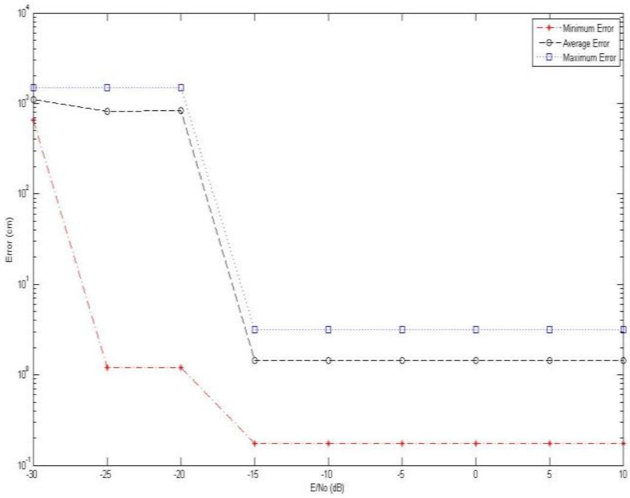

Figure6: Maximum, Minimum, and Average errors in positioning vs. different E/No at Nyquist rate

The values of minimum, average, and maximum errors are close to each other until signal to noise ratio equal to -15 dB. In the cases of decreasing the E/No level below -15 dB, the value of the maximum error increases at high rate. Increasing the noise level at the receiver makes the first pulse not the strongest pulse, so there is a shift in the time of the signal that arrives to the receiver. This shift produces an error in the location of the target.

V. CONCLUSION

In this paper, localization of asset in different locations based on IEEE.802.15.4a"industrial environment" is estimated using a passive TDOA. A new waveform is proposed based on Gaussian waveform to prevent UWB signal to interference with other signals. The scheme is based on dividing the area of interest into a grid with five reference nodes. The location of the reference nodes is simulated to determine the best combination that gives minimum error. The error between the real and estimated position of the target is simulated versus the signal to noise ratio at the receiver at Nyquist rate. The error is stable until E/No decreases below -15 dB. The suddenly increasing in the error produced from shift in time of detection the signal at reference nodes.

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