Ranging detection algorithm for indoor UWB channels and research activities relating to a UWB-RFID localization system

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Contents

• Introduction to UWB-RFID localization
• Indoor UWB channel measurements
• Ranging detection algorithm
• Results on one way ranging accuracy
• Active UWB-RFID localization based on TDOA
Scalable UWB-RFID Positioning System

Motivation
An ultra-wideband (UWB) enabled radio frequency identification (RFID) system
• scalable real time identification, localization, positioning and tracking of objects/nodes.
• scalability to thousands of nodes over area size of hundreds of meters
• applications such as logistics and environmental monitoring and protection
• positioning capability at sub-meter level using low power (<10mW) active tags and (<100 uW) passive tags.

Innovative Ideas
Our innovative ideas are centered on UWB enabled backscatter RFID system architecture. For example, passive tags mounted on the walls will help to guide visually handicapped person to navigate in his home or a shopper to localize his position with respect to the goods that he wish to purchase.

Figure 1: Scalable UWB-RFID Localization System

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Indoor UWB channel measurements

Measurement Campaign Objectives

• Obtain a database of UWB channel profiles in various indoor environments.
• Test UWB ranging accuracy in indoor environment with FCC PSD mask compliance UWB signal and Model the ranging error statistically.
• Analyze the UWB ranging performance in indoor environment and use the analysis to facilitate the ranging parameters setting in both LOS and NLOS cases.
Measurement System Setup

- Agilent 8648B Signal Generator
- Power Splitter
  - Tabor 100 MHz Programmable Pulse Generator (Model 8600)
    - TTL Gating Signal
    - Hp 11720A Pulse Modulator
  - In-House Design UWB Pulse Generator
    - Bandpass Filter
    - Pre-Amp
    - Triggering Signal
  - -6dB Attenuator

- 25 MHz Sinusoid Signal
- 2 MHz Rectangular Pulse Signal
- UWB Signal

- Tx Antenna
- Rx Antenna
  - LNA
  - Agilent 86100B Digital Sampling Oscilloscope
Measurement Setup

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Bi-conical Antenna Pattern

\[ \theta = 45^\circ \]
\[ \varphi = 38.7^\circ \]
\[ r = 1.4\text{cm} \]
\[ R = 3.2\text{cm} \]

Coaxial cable
Test the Omni-directional properties of measurement setup

Max-Min=0.0022V ( = -15.65dB)

Max-Min=200ps
Measurement Environment

Indoor Office

Laboratory Room

Open Hall

Corridor

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## Campaign Summary

<table>
<thead>
<tr>
<th>Environment</th>
<th>Sample Points</th>
<th>Sample Spacing</th>
<th>Maximum Distance</th>
<th>LOS or NLOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor Office</td>
<td>1257</td>
<td>0.2m</td>
<td>26m</td>
<td>LOS and NLOS*</td>
</tr>
<tr>
<td>Lab</td>
<td>271</td>
<td>0.2m</td>
<td>5m</td>
<td>LOS</td>
</tr>
<tr>
<td>Open Hall</td>
<td>61</td>
<td>0.5m</td>
<td>30m</td>
<td>LOS</td>
</tr>
<tr>
<td>Corridor</td>
<td>31</td>
<td>1m</td>
<td>30m</td>
<td>LOS</td>
</tr>
<tr>
<td>Total</td>
<td>1620</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* LOS – Line of Sight  NLOS – Non Line of Sight
**Indoor Office Layout with Measurement Routes**

- 1257 measurement points in indoor environment
- 0.2 meter spacing
- Maximum distance is 26 meters

![Graph showing NLOS and LOS measurements with 691, 267, and 17 values]

![Diagram of indoor office layout with measurement routes and various markers for NDDP, DDP, Transmitting Antenna Position, and Receiving Antenna Route]
Received direct path pulse shape with Tx-Rx distance of 1m
NLOS received waveforms with heavy blockage
Ranging Algorithm Problem Statement

- Time of Arrival ranging systems using impulse radio UWB
- What is the optimum threshold setting and search window size for direct path detection
- How does SNR, LOS and NLOS environments affect these optimum settings


Ranging Performance Analysis

The received signal $r(t)$ is modeled as,

$$r(t) = \alpha_d s(t - \tau_d) + \sum_{i=1}^{L} p_i \alpha_i s(t - \tau_i) + n(t) \quad \text{......... Eq (1)}$$

Where $\alpha_d$ and $\tau_d$ are the amplitude and propagation delay of direct path

$\alpha_i$ and $\tau_i$ are the amplitude and propagation delay of $i^{th}$ multipath

$p_i$ is the polarity of $i^{th}$ multipath

$n(t)$ is the WGN process
After correlated with the pulse template, the resulting waveform within \([ \tau_p - \delta, \tau_p ]\) can be expressed

\[
R_c (t) = \alpha_d R_{ss} (t - \tau_d) + \sum_{i=1}^{M} p_i \alpha_i R_{ss} (t - \tau_i) + R_{ns} (t) \ldots \ldots \text{Eq (2)}
\]

Where \(R_{ss}\) is the autocorrelation function of pulse template

\[
\alpha_M = \alpha_p \quad \text{and} \quad \tau_M = \tau_p
\]

Let us define: \(\rho_d = \alpha_d / \alpha_p\) (Normalized direct path amplitude)

\[
\beta_d = \tau_p - \tau_d \quad \text{(Time difference between Peak path and Direct path)}
\]
Conclusion on Ranging settings for LOS

- According to measurement results, the direct path is not the largest path in 17 profiles out of 289 profiles in LOS.
- For LOS, simple strategy is enough: setting search period $\delta > 20\text{ns}$ and detection threshold $y = m \alpha_p$ with $m = 0.5\sim0.6$
Distribution of NLOS Direct Path Amplitude and Time of Arrival

\[
f_{\rho_d}(\rho_d \neq 1) = \frac{1}{\sqrt{2\pi}Q\left(-\frac{\mu}{\sigma_{\rho}}\right)} \sigma_{\rho} \rho_d \exp\left[-\frac{(\ln \rho_d - \mu)^2}{2\sigma_{\rho}^2}\right]
\]

where \( Q(x) = \int_{-\infty}^{x} \frac{1}{\sqrt{2\pi}} \exp\left[-\frac{x^2}{2}\right] dx \); \( f_{\beta_d}(\beta_d \neq 0) = \frac{\beta_d}{\eta} \exp\left[-\frac{\beta_d}{\eta}\right] \)

\( \ldots \ldots \text{Eq (3)} \)

\( \ldots \ldots \text{Eq (4)} \)
- Evaluate the performance by large error probability (\(|\text{Estimated arrival time of direct path} - \text{true arrival time of direct path}| > T_c/2\))

- The large error probability is related to three events

\[
H_1 = \{\beta_d > \delta\}
\]

\[
H_2 = \{\beta_d \leq \delta\} \cap \{\|\alpha_d + n_{ns}\| < \gamma\}
\]

\[
H_3 = \{Z_{\max} > \gamma\} \cap \{\|\alpha_d + n_{ns}\| \geq \gamma\}
\]

Where, \(Z_{\max} = \sup\{|R_{ns}(t)|\}, t \in [\tau_p - \delta, \tau_p]\) and \(\delta \geq \beta_d\).

\[
n_{ns} = R_{ns}(\tau_p),
\]

- Since three events are exclusive, the large error probability is

\[
P_{Lgr}(\gamma, \delta) = P(H_1) + P(H_2) + P(H_3) \quad \ldots \ldots \text{Eq (5)}
\]
Ignoring the intermediate derivation process, the final equation will be,

\[
P_{Lgr} = 1 - P_0 \exp\left[-\frac{\delta}{\eta}\right] \left(1 - \Psi(m, \kappa)\right) + \left(1 - (1 - P_0) \Gamma(m, \kappa) - P_0 \Psi(m, \kappa)\right)
\]

\[
\left(\exp\left(-\frac{\delta}{\eta}\right) - \exp\left(-\frac{2\delta}{\Omega(m, \kappa)}\right)\right) \left(\frac{2\eta P_0 - \Omega(m, \kappa)}{2\eta - \Omega(m, \kappa)}\right)
\]

\[\text{Eq (6)}\]

Where \( m = \frac{\gamma}{\alpha_p} \) is normalized threshold

\( \kappa = \frac{\alpha_p}{\sigma_{ns}} \) is signal-to-noise (SNR) ratio
Comparison of simulation and analytical results, (Search window size=100nS)
Adaptive ranging parameters Setting

For NLOS, if channel parameters are given, numerical search may be performed with Eq(6) to obtain the optimum setting.
Performance curves for various SNR and search windows size

$k=10\,dB$

$k=15\,dB$

$k=20\,dB$

$k=30\,dB$
Conclusion on Ranging settings for NLOS

For NLOS, if channel parameters are not available, a two-state threshold settings method is proposed:
(1). $\delta$ is predefined and fixed. A worst-case false alarm rate $P_{fls}$ is predefined

$$m = \frac{1}{\kappa} \sqrt{2 \ln \left( \frac{-\delta \lambda_0}{\ln(1 - P_{fls})} \right)}$$

$\lambda_0$ is a parameter related to the RMS bandwidth of pulse template

(2). If the calculated $m$ for a particular $\kappa$ is larger than 1, the largest path is taken as the direct path and the earliest path searching path does not initialized.
Performance of optimum setting by numerical searching versus performance of two-state setting strategy with $\delta = 50\text{ns}$
## Ranging Error Performance

- Comparison of Coherent (CLEAN) and Non-coherent (Energy detection)

<table>
<thead>
<tr>
<th></th>
<th>Indoor Office</th>
<th>Lab</th>
<th>Open Hall</th>
<th>Corridor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LOS</td>
<td>NLOS</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>By Non-Coherent Detection</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (m)</td>
<td>0.018</td>
<td>4.336</td>
<td>0.011</td>
<td>0.031</td>
</tr>
<tr>
<td>STD. (m)</td>
<td>0.015</td>
<td>10.220</td>
<td>0.014</td>
<td>0.019</td>
</tr>
<tr>
<td>Max (m)</td>
<td>0.067</td>
<td>93.094</td>
<td>0.077</td>
<td>0.080</td>
</tr>
<tr>
<td><strong>By Coherent Detection</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (m)</td>
<td>0.015</td>
<td>2.004</td>
<td>0.010</td>
<td>0.015</td>
</tr>
<tr>
<td>STD. (m)</td>
<td>0.010</td>
<td>3.784</td>
<td>0.013</td>
<td>0.012</td>
</tr>
<tr>
<td>Max (m)</td>
<td>0.051</td>
<td>38.505</td>
<td>0.080</td>
<td>0.049</td>
</tr>
</tbody>
</table>
Ranging Error Performance

- CDF of ranging errors $|\varepsilon|$ for LOS and NLOS conditions.

- Probability of $|\varepsilon|$ < Abscissa for non-coherent and coherent detection.
Active UWB-RFID Localization

Active UWB-RFID:
• TDOA computation in central controller
• Time synchronization among locators are through a hard wire
Active UWB-RFID Localization using TDOA

Lower bound of positioning error

Measurement Environment

Positioning error between UWB measured locations and actual locations of 121 points. Most locations positioning error < 10cm

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End of Presentation

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