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

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- 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.

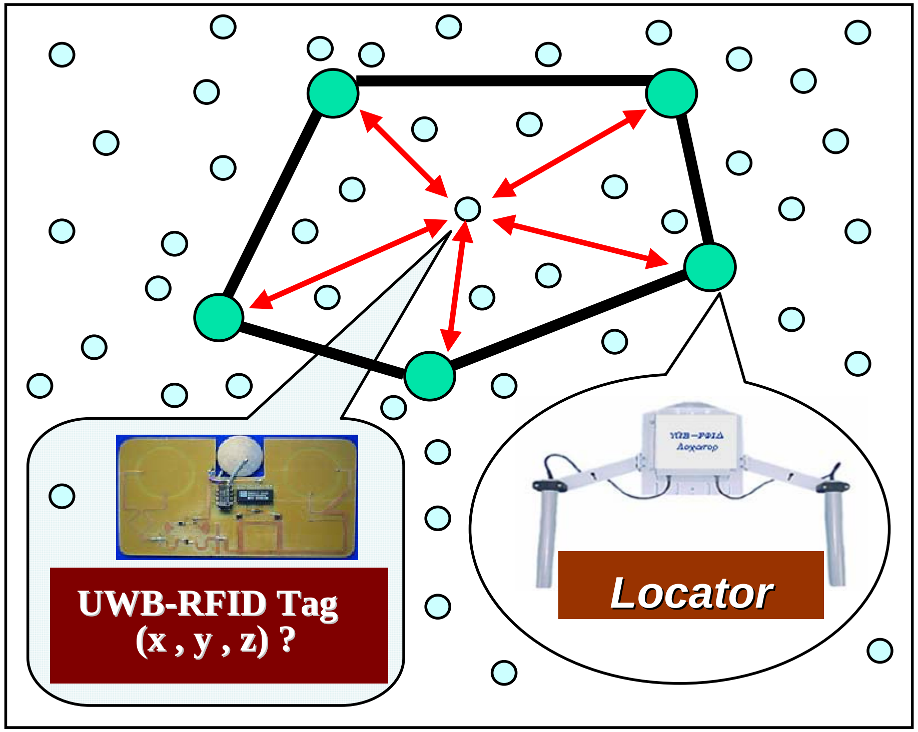


Figure 1: Scalable UWB-RFID Localization System

Innovative Ideas

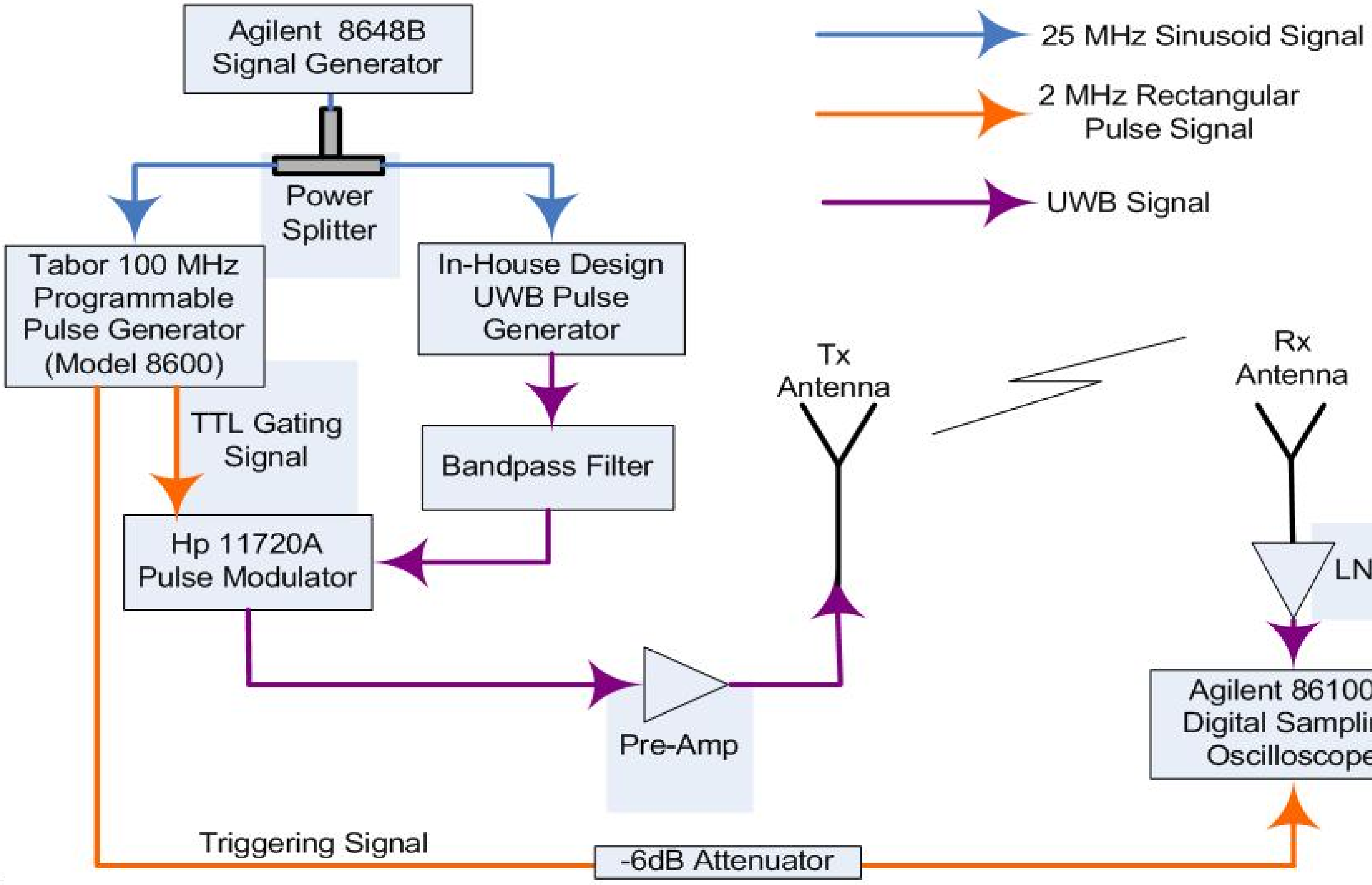
Our innovative ideas are centered on UWB enabled backscatter RFID system architecture. For example, passive tags mounted on the walls will help to guide visually handicapped person to navigate in his home or a shopper to localize his position with respect to the goods that he wish to purchase

Indoor UWB channel measurements

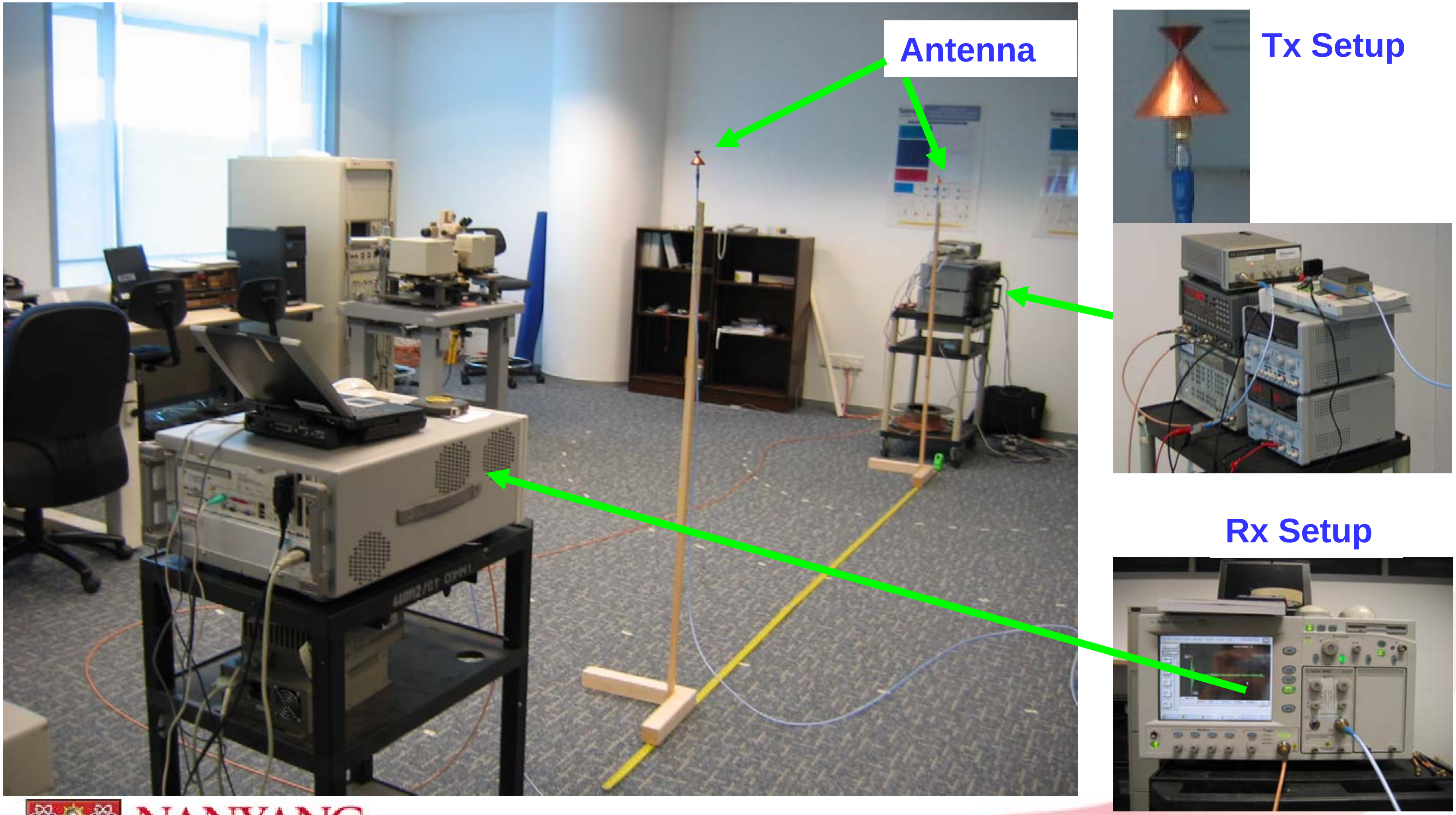
Measurement Campaign Objectives

- 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.

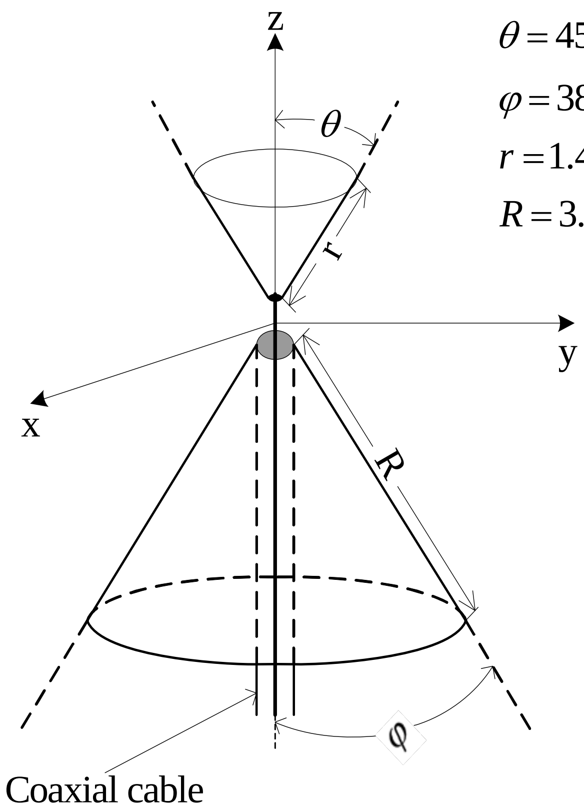
Measurement System Setup



Measurement Setup



Bi-conical Antenna Pattern

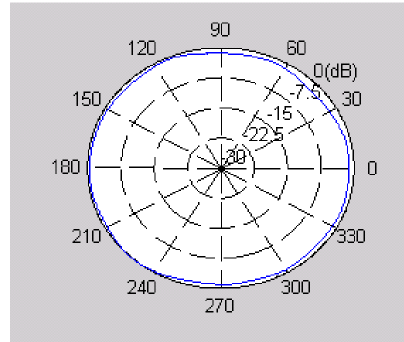


$\theta = 45^0$

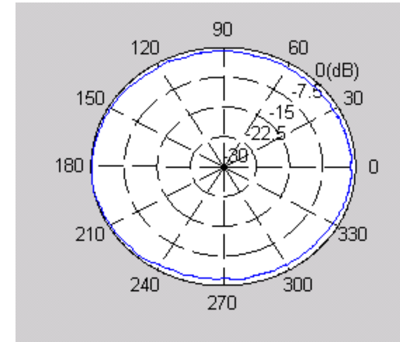
$\varphi = 38.7^0$

$r = 1.4cm$

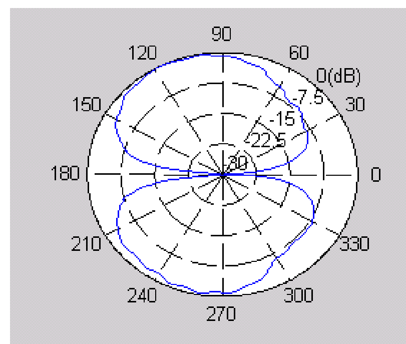
$R = 3.2cm$



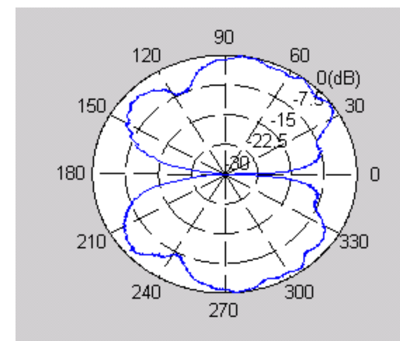
3.1GHz Azimuth Plane



10.6 GHz Azimuth Plane

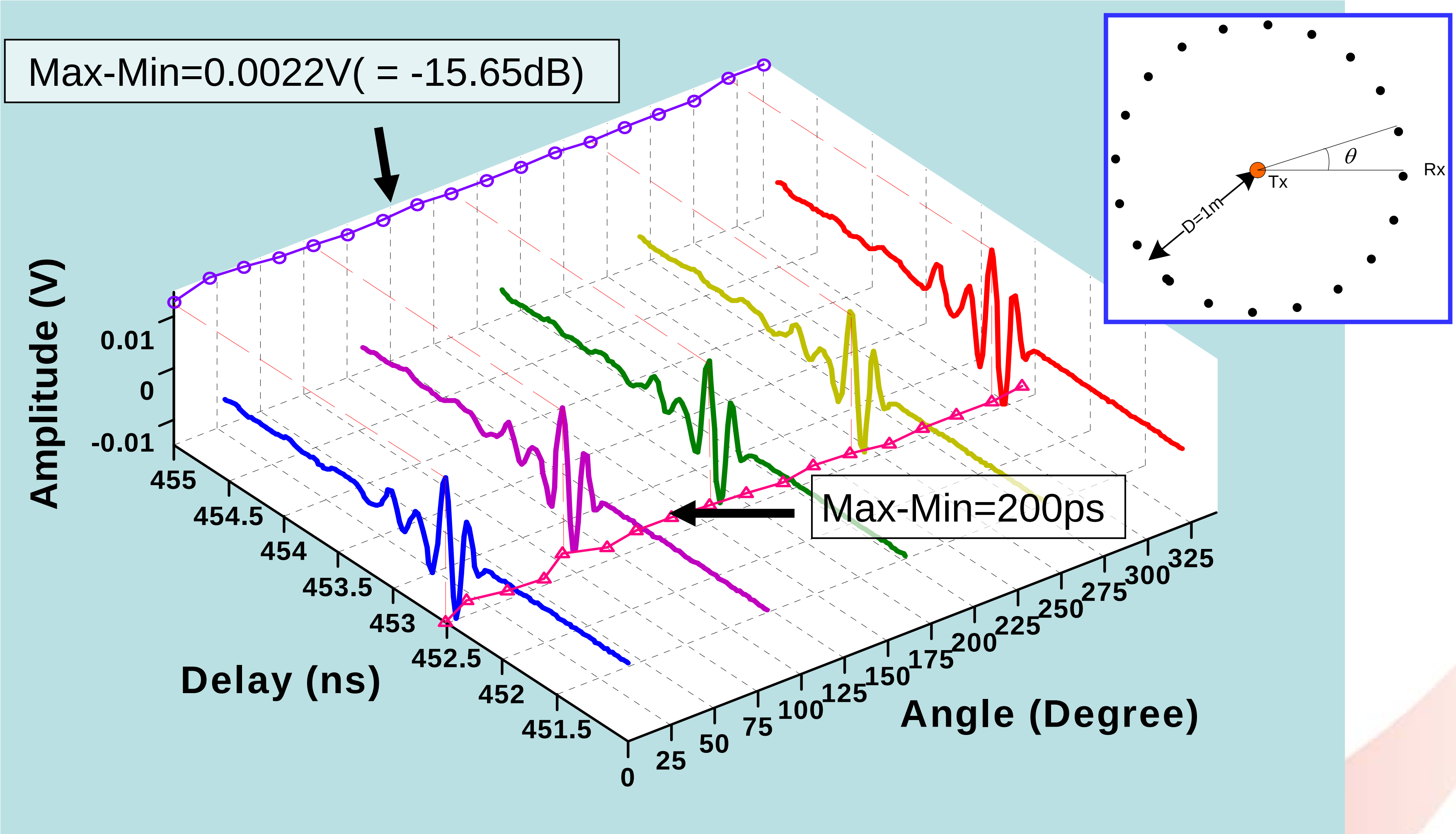


3.1GHz Elevation Plane



10.6 GHz Elevation Plane

Test the Omni-directional properties of measurement setup



Measurement Environment

Indoor Office

Laboratory Room

Open Hall

Corridor

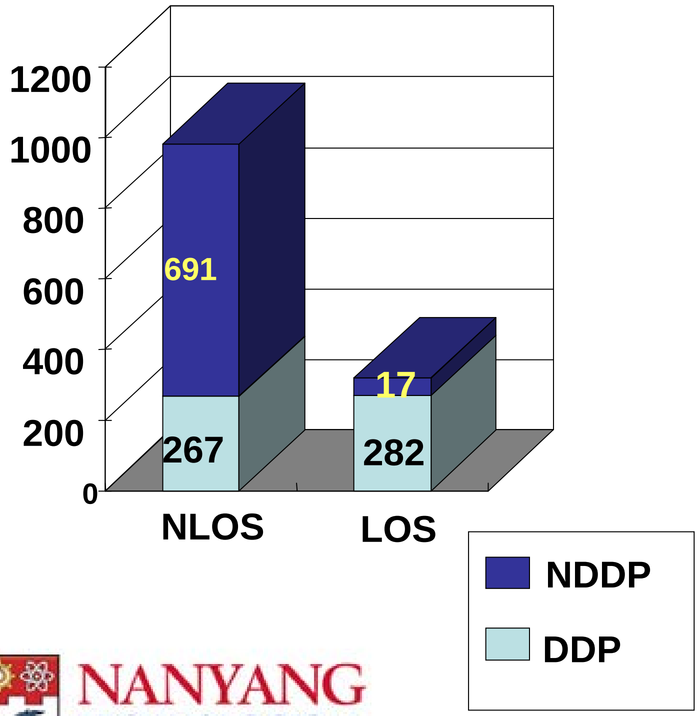
Campaign Summary

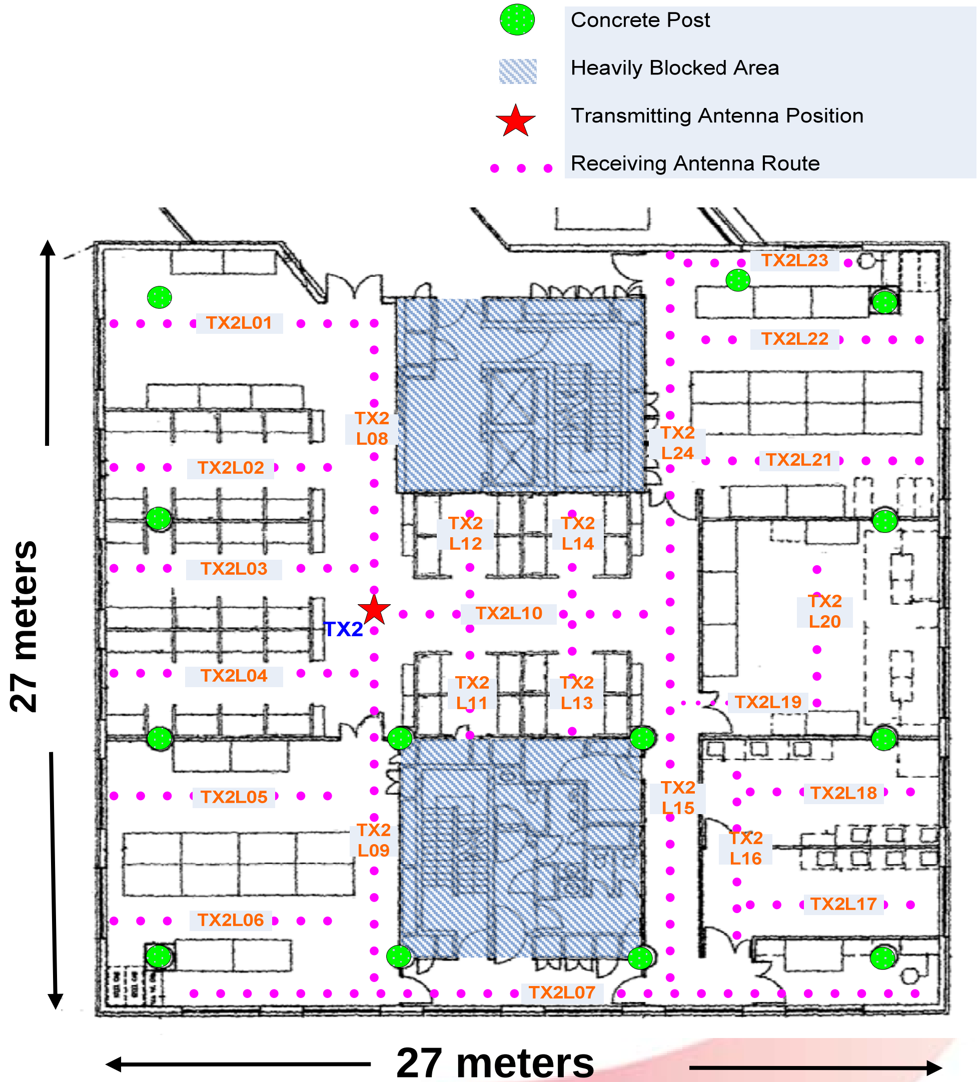
Environment	Sample Points	Sample Spacing	Maximum Distance	LOS or NLOS
Indoor Office	1257	0.2m	26m	LOS and NLOS*
Lab	271	0.2m	5m	LOS
Open Hall	61	0.5m	30m	LOS
Corridor	31	1m	30m	LOS
Total	1620			

*** LOS – Line of Sight   NLOS – Non Line of Sight**

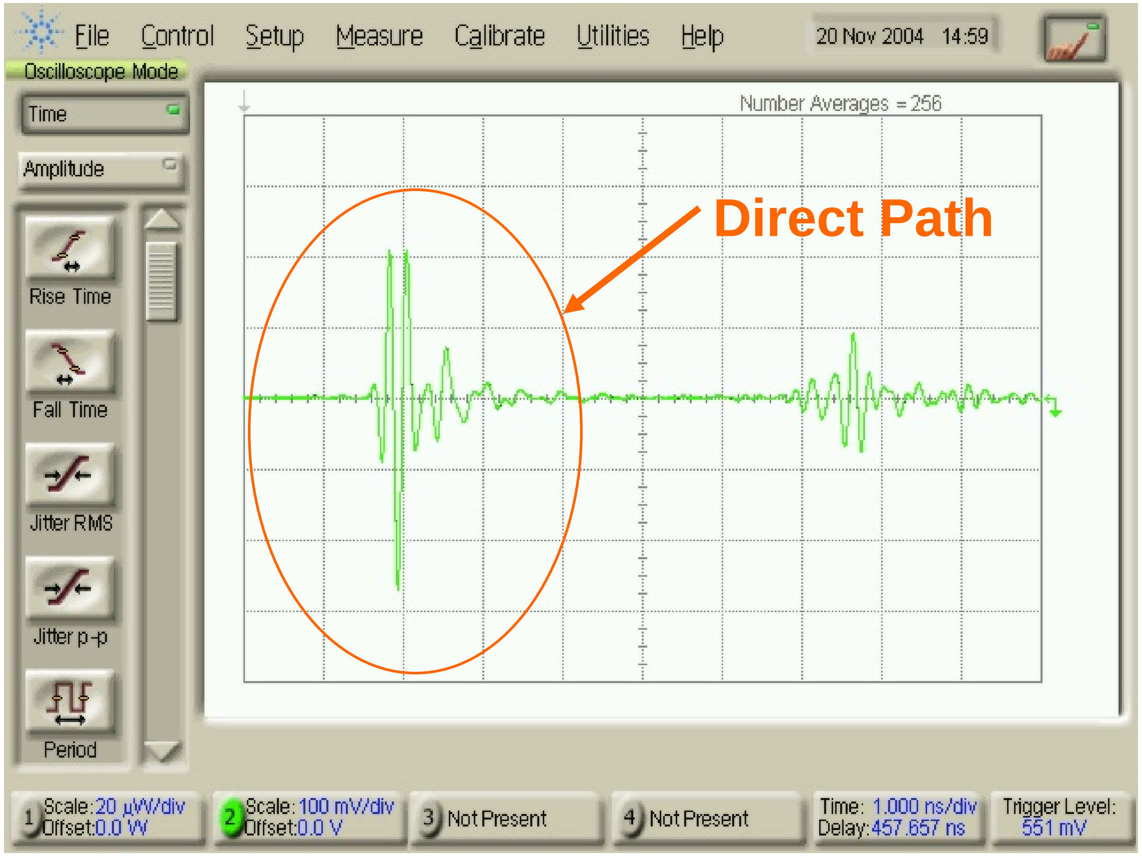
Indoor Office Layout with Measurement Routes

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

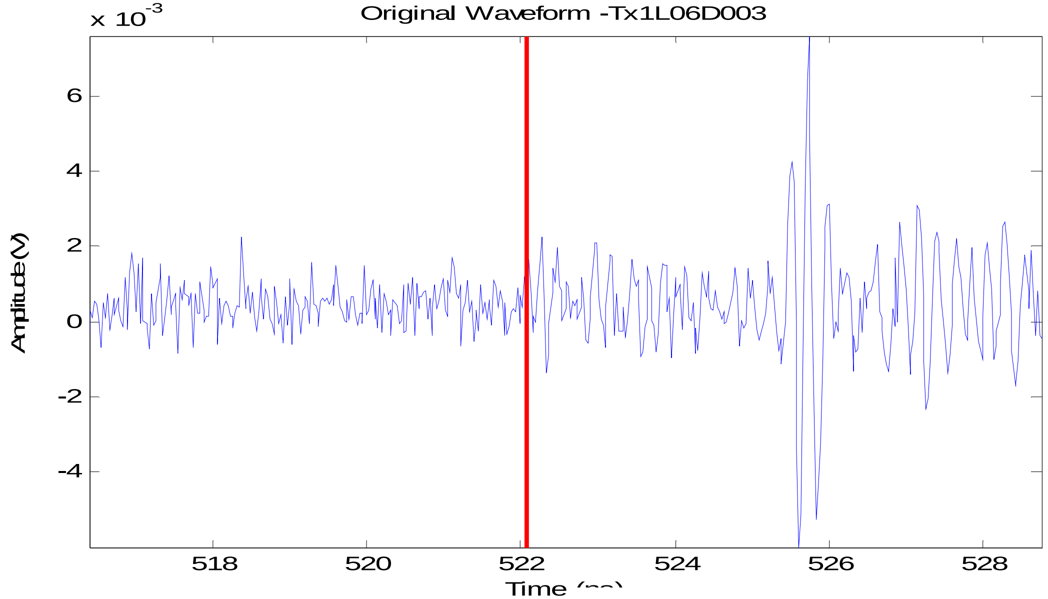


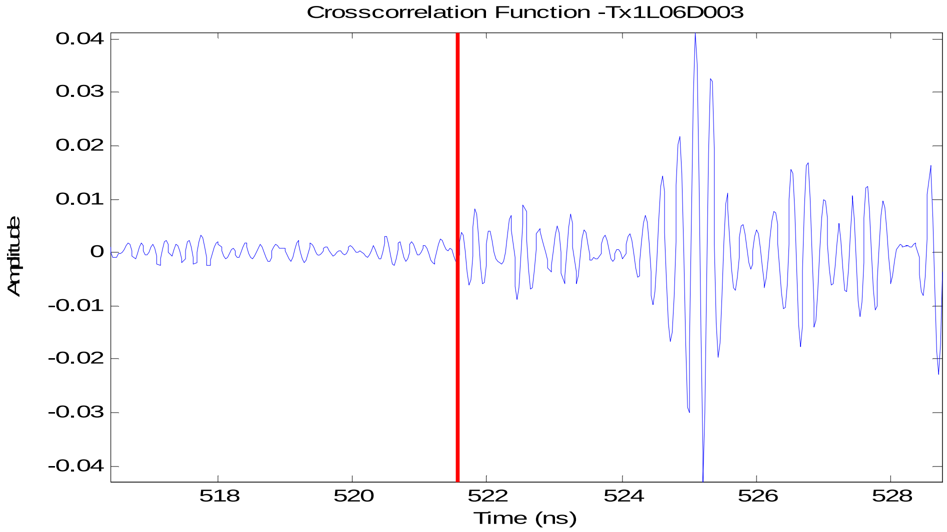


Received direct path pulse shape with Tx-Rx distance of 1m



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 α_d and τ_d are the amplitude and propagation delay of direct path

α_i and τ_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 [τp - δ, τp] can be expressed

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

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

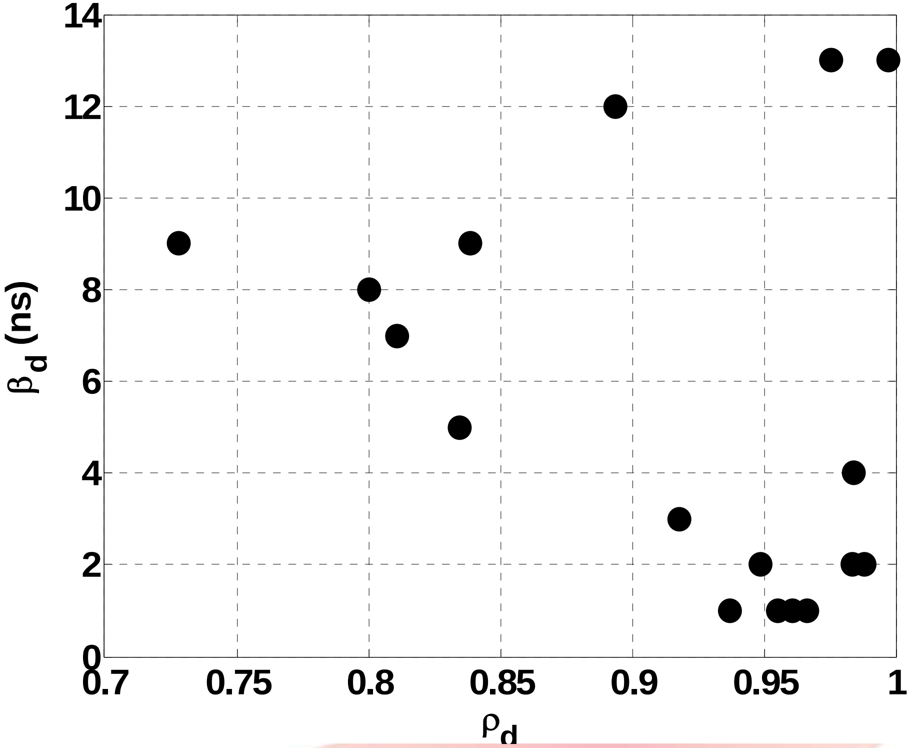
$$\alpha_M = \alpha_p \text{ and } \tau_M = \tau_p$$

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

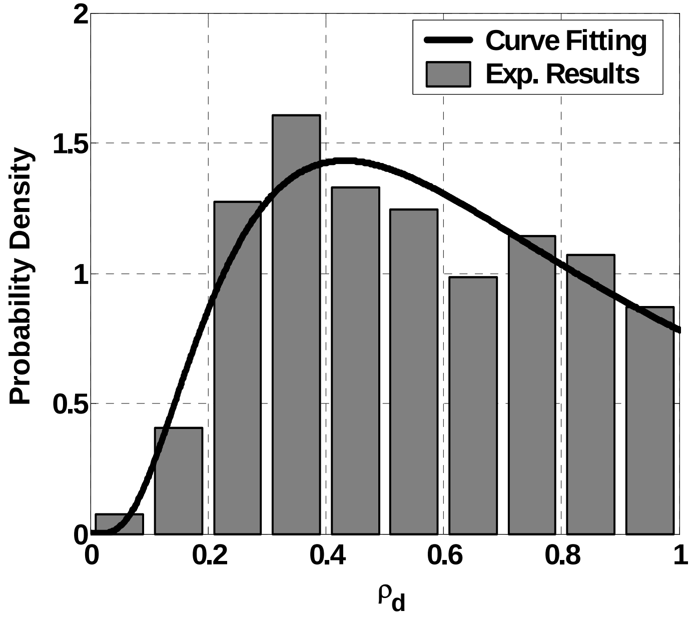
$\beta_d = \tau_p - \tau_d$ (Time difference between Peak path and Direct path)

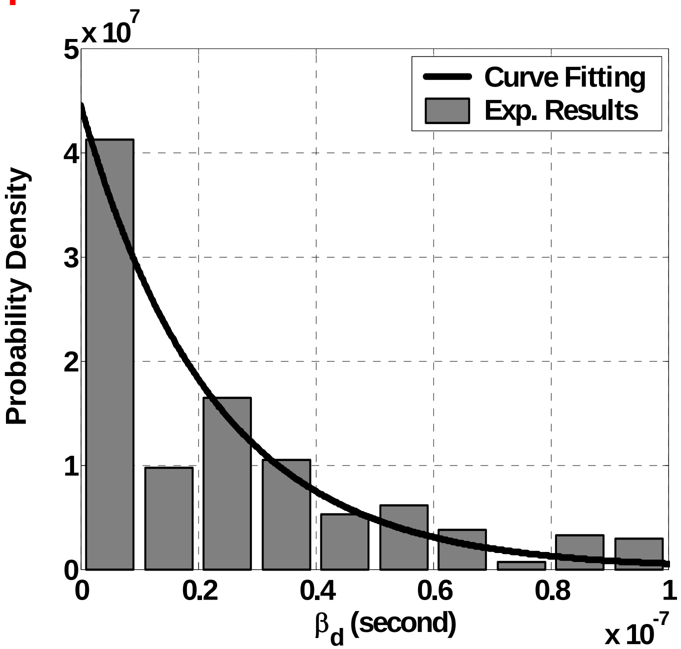
Conclusion on Ranging settings for LOS

- According to measurement results, the direct path is not the largest path in17 profiles out of 289 profiles in LOS.
- For LOS, simple strategy is enough:
setting search period δ *>20ns* and detection threshold γ *=m* α_p with *m=0.5~0.6*



Distribution of NLOS Direct Path Amplitude and Time of Arrival





$$f_{\rho_d}\left(\rho_d \mid \rho_d \neq 1\right) = \frac{1}{\sqrt{2\pi}Q\left(-\mu/\sigma_\rho\right)\sigma_\rho\rho_d}\exp\left[-\frac{\left(\left(\ln\rho_d\right)-\mu\right)^2}{2\sigma_\rho{}^2}\right]$$ …….. *Eq (3)*

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

…….. *Eq (4)*

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- Evaluate the performance by large error probability (|Estimated arrival time of direct path – true arrival time of direct path| > $T_c/2$)
- The large error probability is related to three events

$$H_1 = \{\beta_d > \delta\}$$

$$H_2 = \left\{\beta_d \le \delta\right\} \cap \left\{\left|\alpha_d + n_{ns}\right| < \gamma\right\}$$

$$H_3 = \left\{Z_{\max} > \gamma\right\} \cap \left\{\left|\alpha_d + n_{ns}\right| \ge \gamma\right\}$$

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

$n_{ns} = R_{ns}(\tau_p)$,

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

$$P_{Lgr}(\gamma,\delta) = P(H_1) + P(H_2) + P(H_3) \quad \text{……….} \textit{ Eq (5)}$$

Ignoring the intermediate derivation process , the final equation will be,

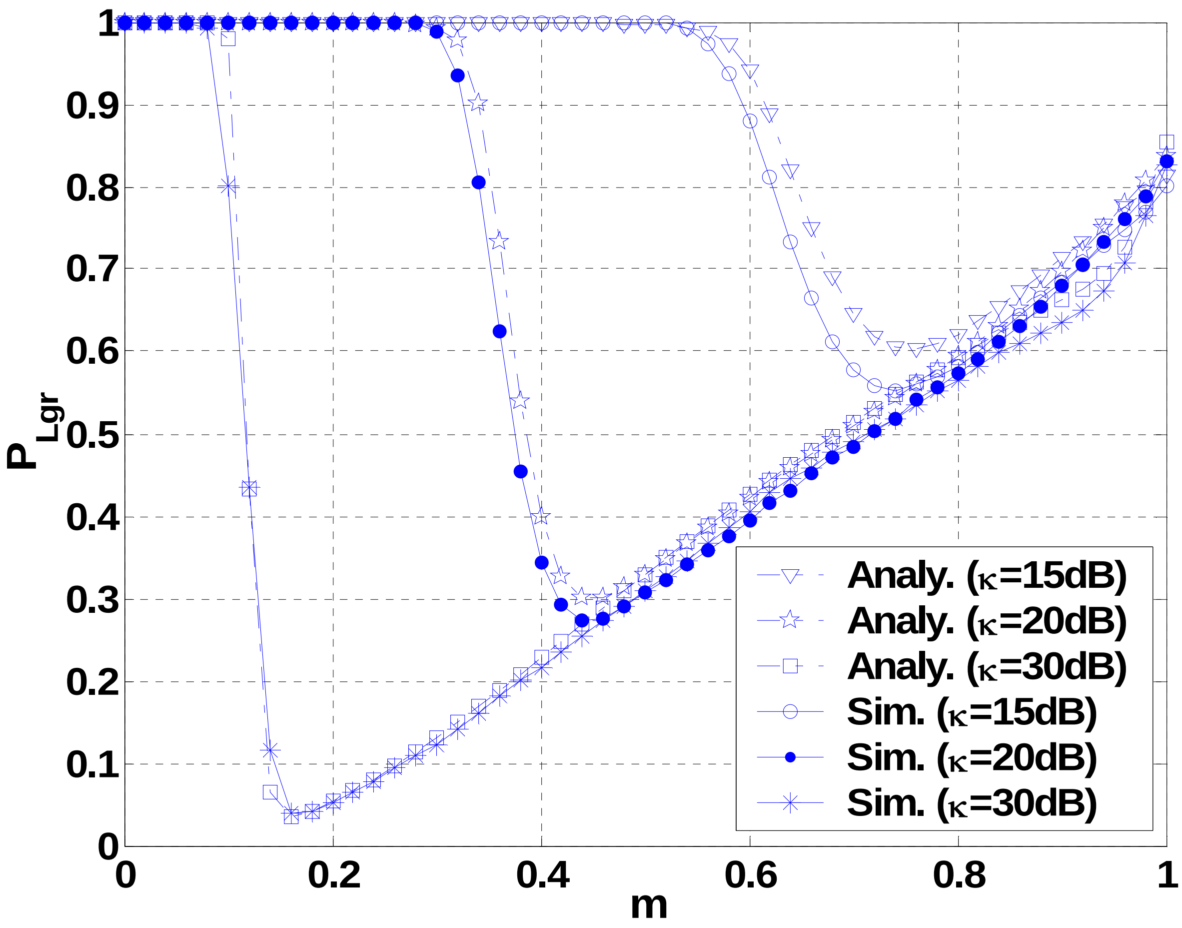
$$P_{Lgr} = 1 - P_0 \exp\left[-\frac{\delta}{\eta}\right]\left(1-\Psi\left(m,\kappa\right)\right) + \left(1-\left(1-P_0\right)\Gamma\left(m,\kappa\right) - P_0\Psi\left(m,\kappa\right)\right)$$

$$\bullet\left(\exp\left[-\frac{\delta}{\eta}\right] - \exp\left[-\frac{2\delta}{\Omega\left(m,\kappa\right)}\right]\right)\left(\frac{2\eta P_0 - \Omega\left(m,\kappa\right)}{2\eta - \Omega\left(m,\kappa\right)}\right) \quad \text{.......................}Eq\ (6)$$

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

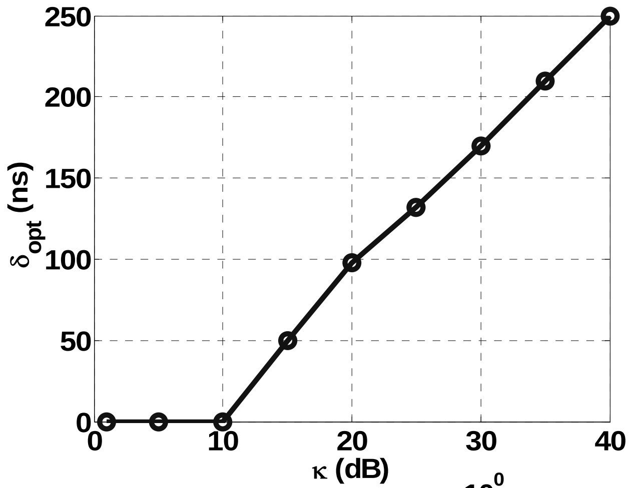
$\kappa = \frac{\alpha_p}{\sigma_{ns}}$ is signal-to-noise (SNR) ratio

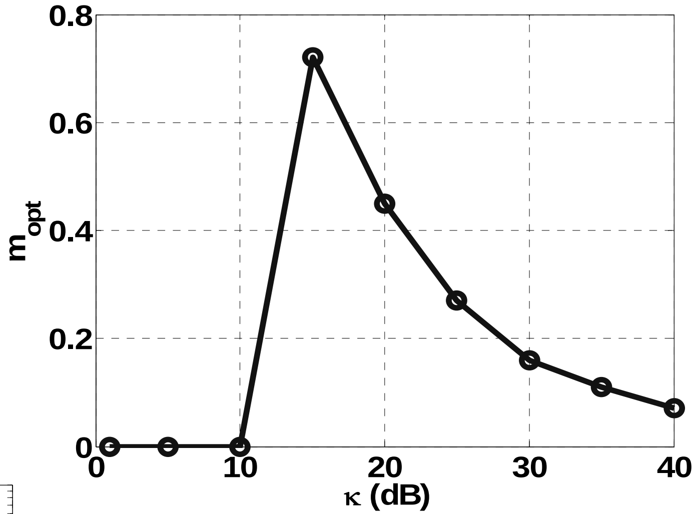
Comparison of simulation and analytical results, (Search window size=100nS)

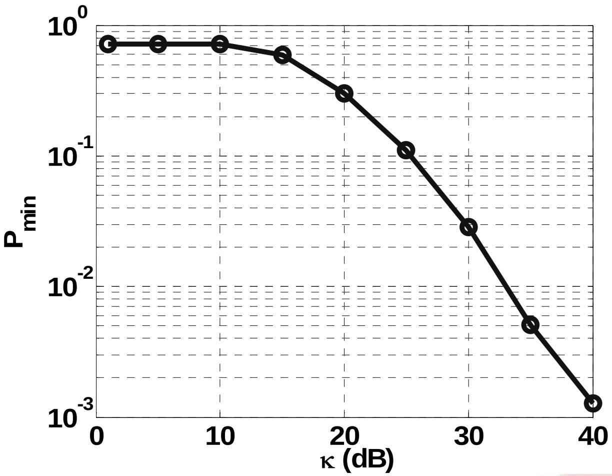


Adaptive ranging parameters Setting

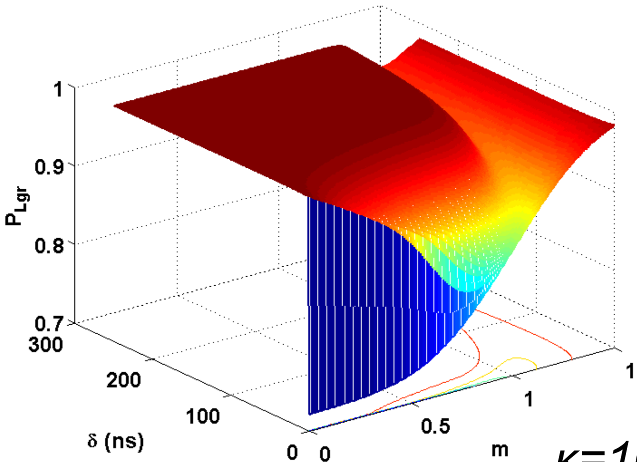
For NLOS, if channel parameters are given, numerical search may be performed with *Eq(6)* to obtained the optimum setting



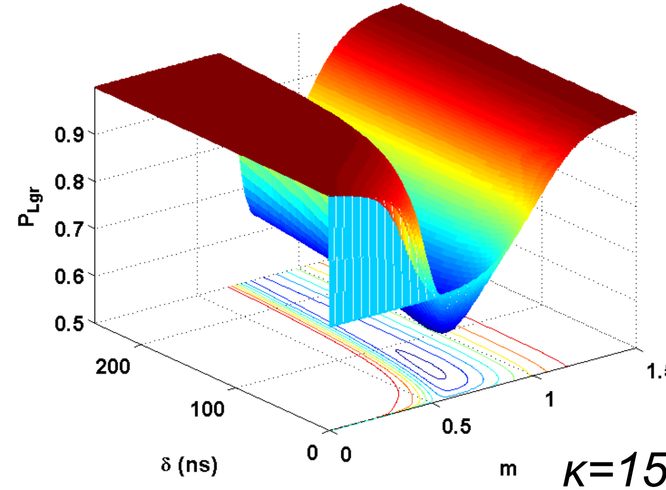




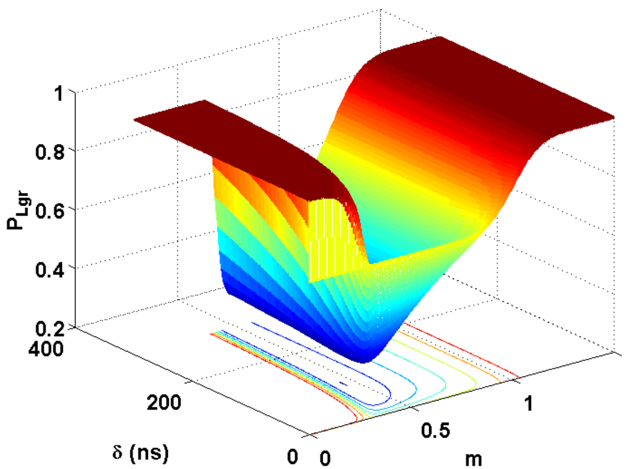
Performance curves for various SNR and search windows size



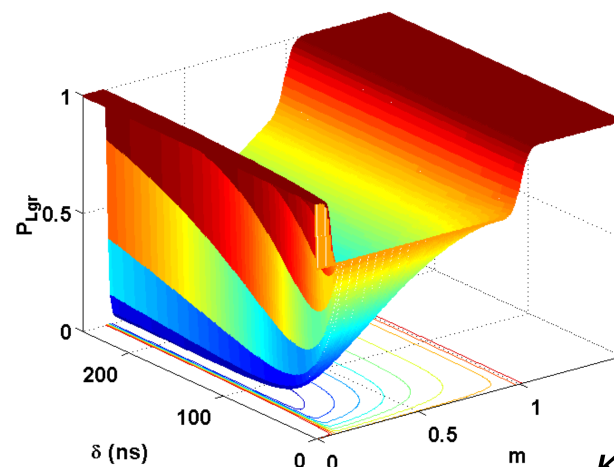
κ=10dB



κ=15dB



κ=20dB



κ=30dB

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Conclusion on Ranging settings for NLOS

For NLOS, If channel parameters are not available, a two-state threshold settings method is proposed:

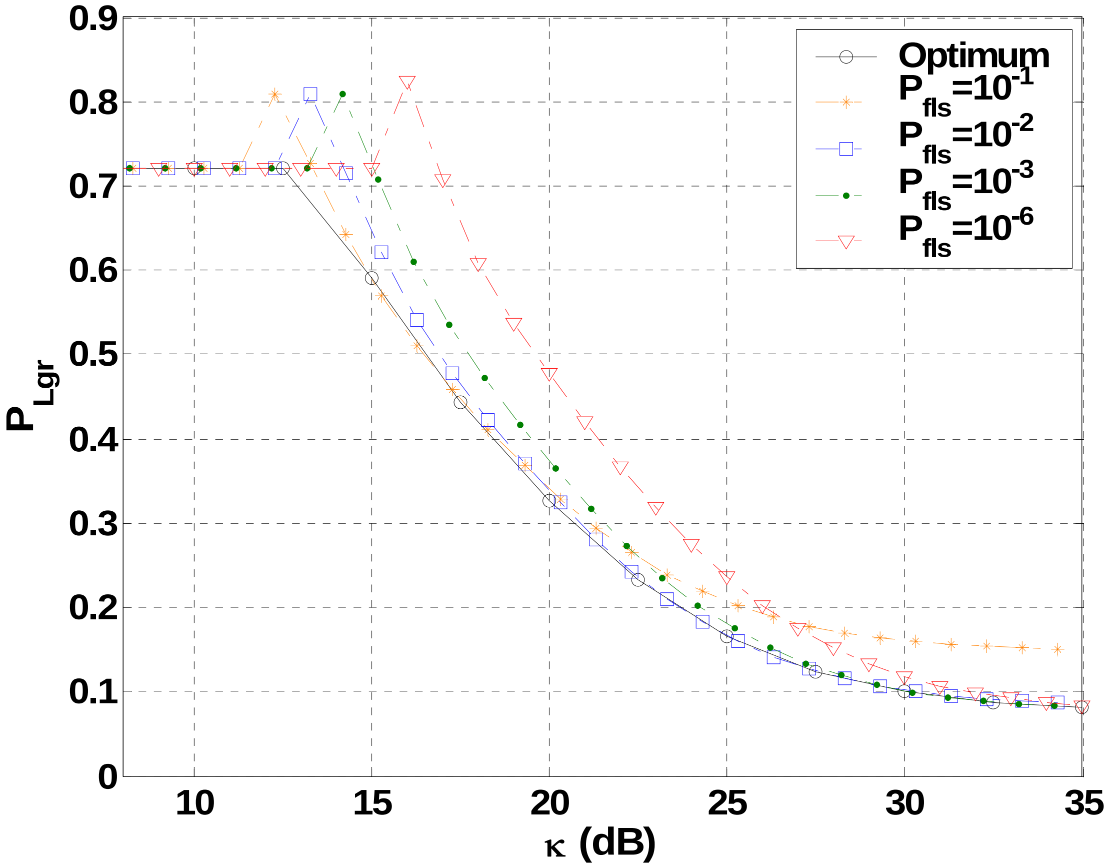
(1). δ is predefined and fixed. A worst-case false alarm rate P_{fls} is predefined

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

λ_0 is a parameter related to the RMS bandwidth of pulse template

(2). If the calculated *m* for a particular κ 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 δ =50ns

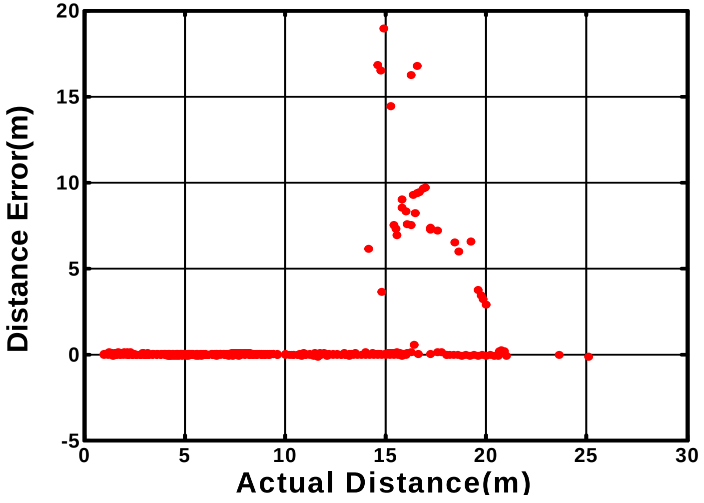


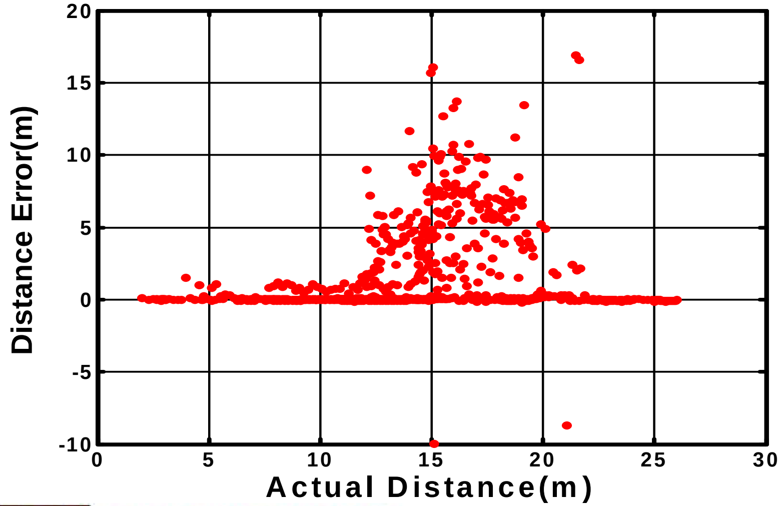
Ranging Error Performance

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

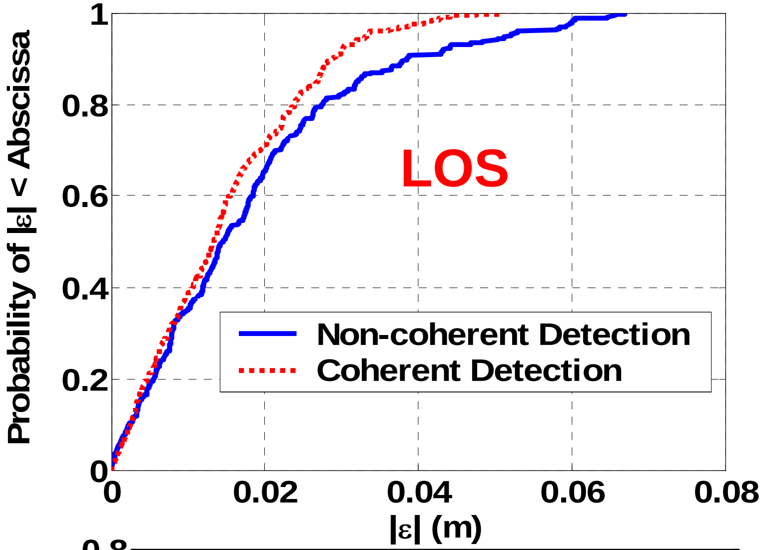
	Indoor Office LOS	Indoor Office NLOS	Lab	Open Hall	Corridor
By Non-Coherent Detection					
Mean (m)	0.018	4.336	0.011	0.031	0.020
STD. (m)	0.015	10.220	0.014	0.019	0.015
Max (m)	0.067	93.094	0.077	0.080	0.056
By Coherent Detection					
Mean (m)	0.015	2.004	0.010	0.015	0.011
STD. (m)	0.010	3.784	0.013	0.012	0.008
Max (m)	0.051	38.505	0.080	0.049	0.031

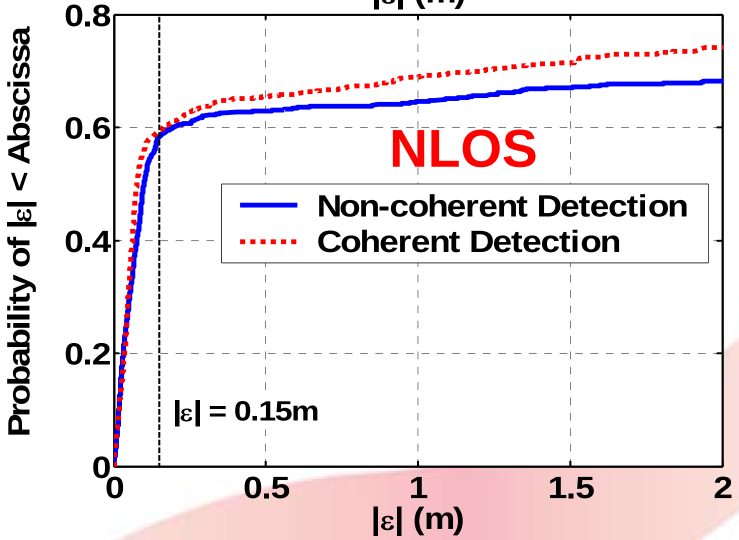
Ranging Error Performance



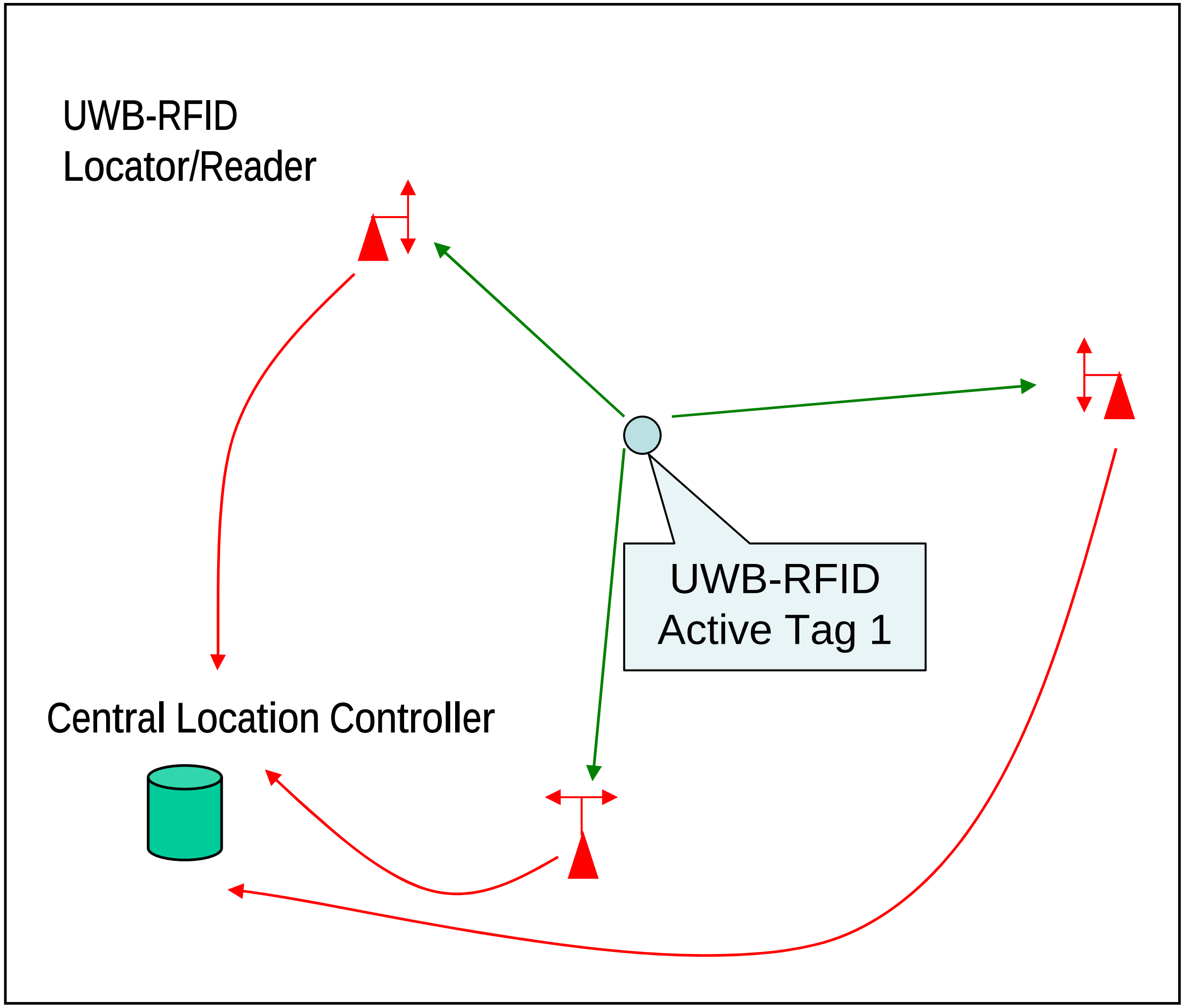


- CDF of ranging errors | ε |





Active UWB-RFID Localization

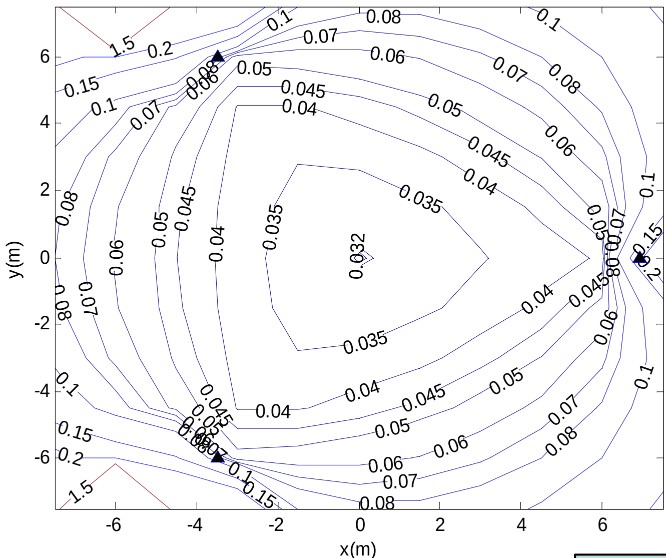


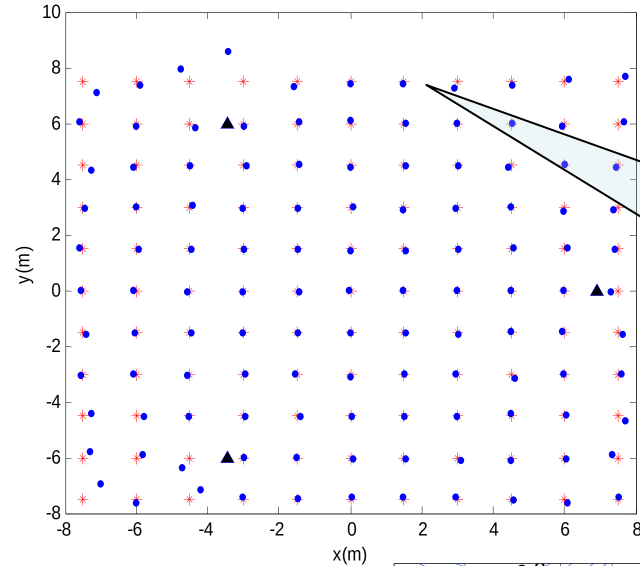
Active UWB-RFID:

- TDOA computation in central controller
- Time synchronization among locators are through a hard wire

Active UWB-RFID Localization using TDOA

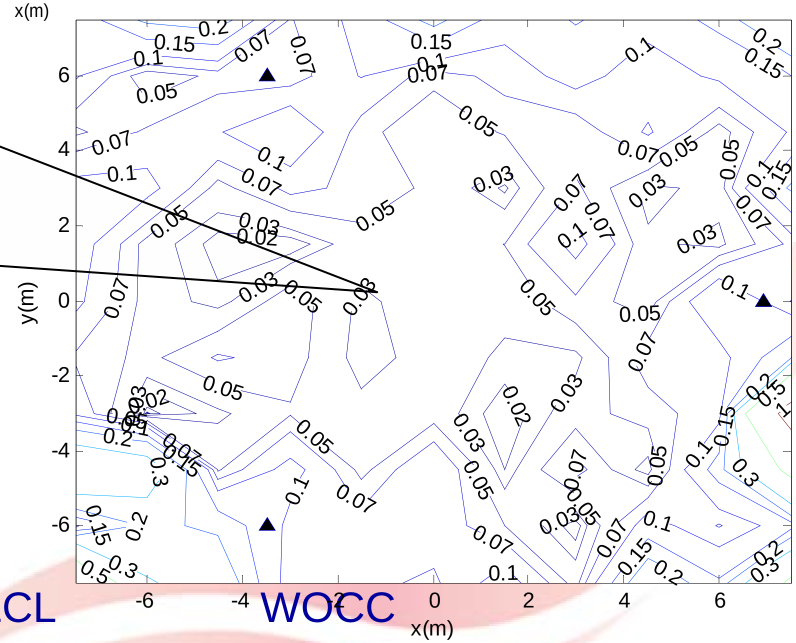
Lower bound of positioning error





estimated locations (blue dots) vs. actual locations (red star)

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



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End of Presentation

Thank you for your attendance

Acknowledgement

(i) Mr Xu Chi – Research Engineer and Part time PhD student
(ii) Mr Fang Chao – Research Engineer and Part time PhD student
(iii) Mr Hu Sanming – International attachment PhD student from SEU, Nanjing China
(iv) Ms Xu Jun – Full time PhD student
(v) Mr Zhou Yuan – Full time PhD student (AGS scholar)
(vi) Ms Jiang Jisu – Full time PhD student
(vii) Ms Thida Than – Research Engineer