The Influence of Antenna Directivity on Accuracy of UWB Ranging

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MCRG Seminar

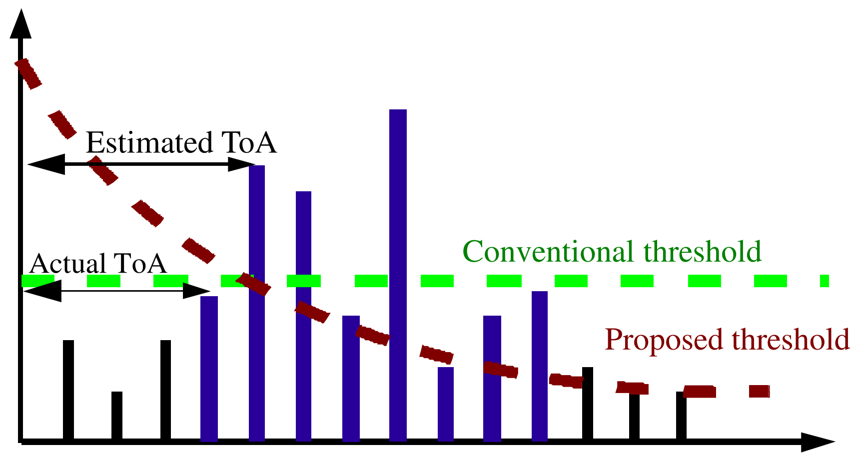
Introduction (1)- ToA based ranging

- UWB signals allow accurate ranging using ToA techniques.
- Among reported ToA estimation schemes, threshold-based ToA estimators have attracted interest due to simplicity.
- *M.Dashti et al. (PIMRC,Sep-09)*: a threshold-based ToA estimation approach was proposed which minimize the range error by setting the threshold as a function of delay.

Introduction (2) - ToA based ranging

ToA estimation algorithm:

- ❑ Received samples are compared to an appropriate threshold.
- ❑ Set the threshold as a function of delay.
- ❑ First sample crossing the respective threshold value is estimated as ToA .



- Tx and Rx nodes are positioned at known coordinates (assumed they are synchronized)

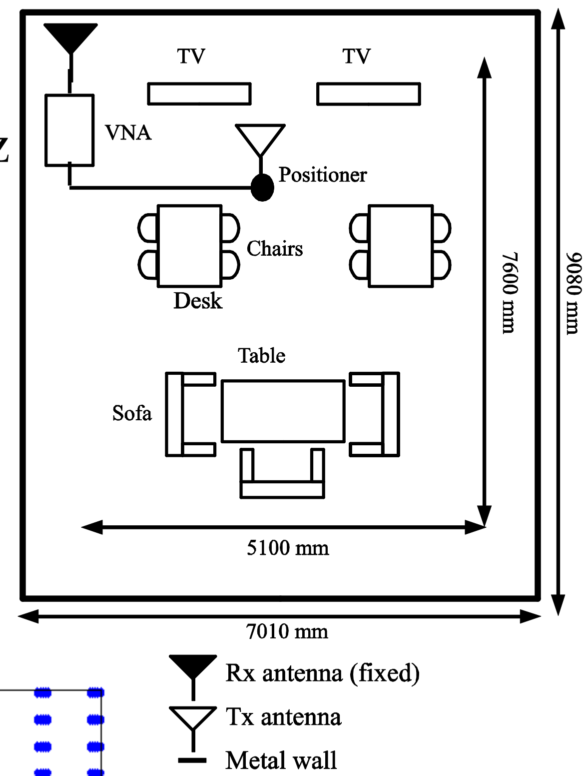
  Tx-Rx measured distance: $d = \tau_{\mathrm{FAP}} \times c$ (c: speed of light; τ_{FAP}: propagation delay of first-arrival-path (FAP))

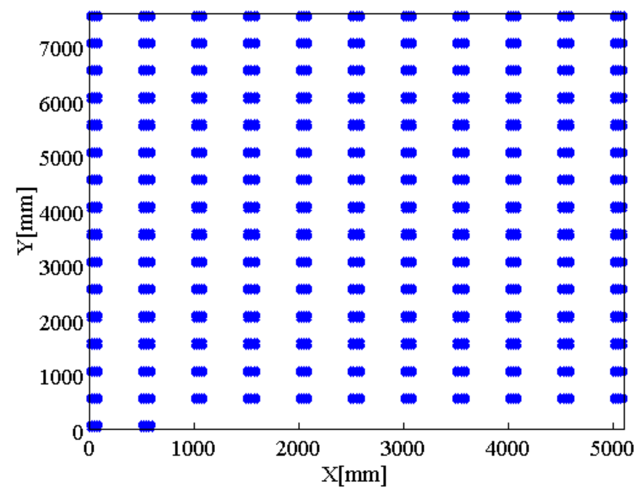
  Ranging error: $e = d - d_{\mathrm{r}}$

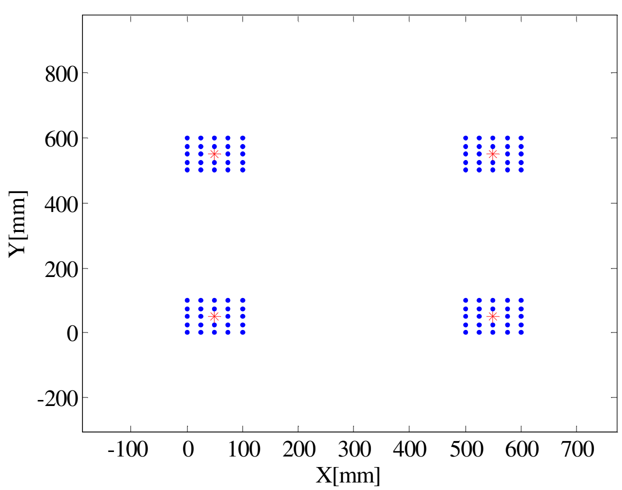
Introduction (3)- Measurement scenario

A database of UWB CIR measurements at 3.1-10.6 GHz in an office room was collected.

- ✓5 × 5 array formed on horizontal plane
- ✓Array measurement performed in 168 positions
- ✓In total 4200 spatial samples measured on Tx
- ✓Inter-array distance 500 mm
- ✓Inter-element spacing in the array is 25 mm







Outline

Purpose of this work:

- Investigate antenna radiation pattern effect on ToA estimation (using the existing measurement data)

Steps:

- Existing data is re-processed to create an arbitrary form of pattern.
  - Considering only the 2-D azimuthal pattern
- ToA estimation algorithm is applied to the new data set (resulting from modified pattern)
- The results of ranging analysis using data with and without antenna synthesizes are compared.

Patterns Synthesis

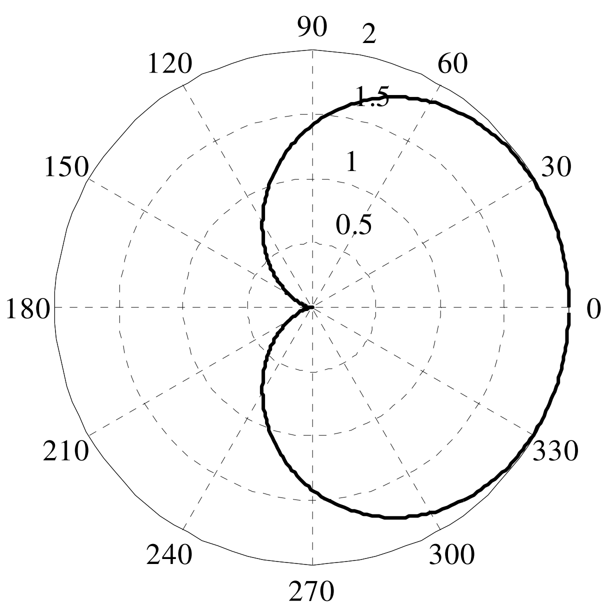
- Virtual array principle for generating different radiating patterns
  - Azimuthal radiation patterns of an antenna can be expressed as the Fourier expansion

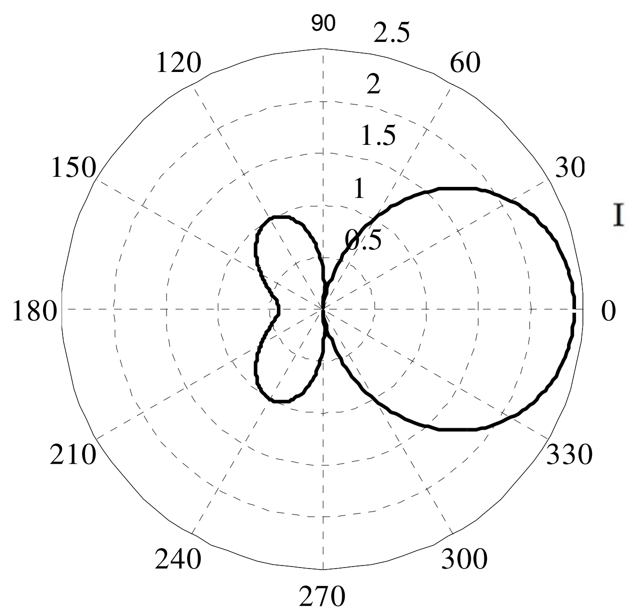
$$E(\phi) = \sum_{m=-M}^{M} Q^{(m)} e^{jm\phi} = \sum_{m=-M}^{M} E^{(m)}(\phi)$$

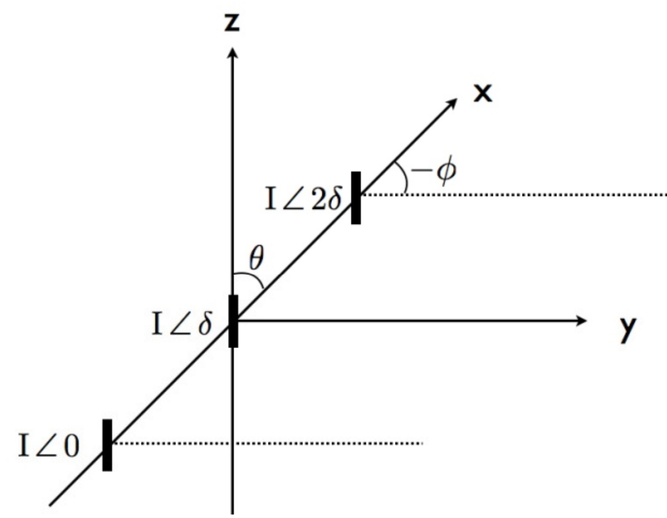
If we are able to generate all modes independently using the virtual array, we can then generate any arbitrary patterns as a weighted sum of these mode patterns.

Synthesis of a dipole array pattern using the basis patterns

- Synthesize patterns using exponential patterns as basis functions
  - Determine the azimuthal pattern function with desired directivity
    - A linear N-elements array of dipoles oriented along the z-axis



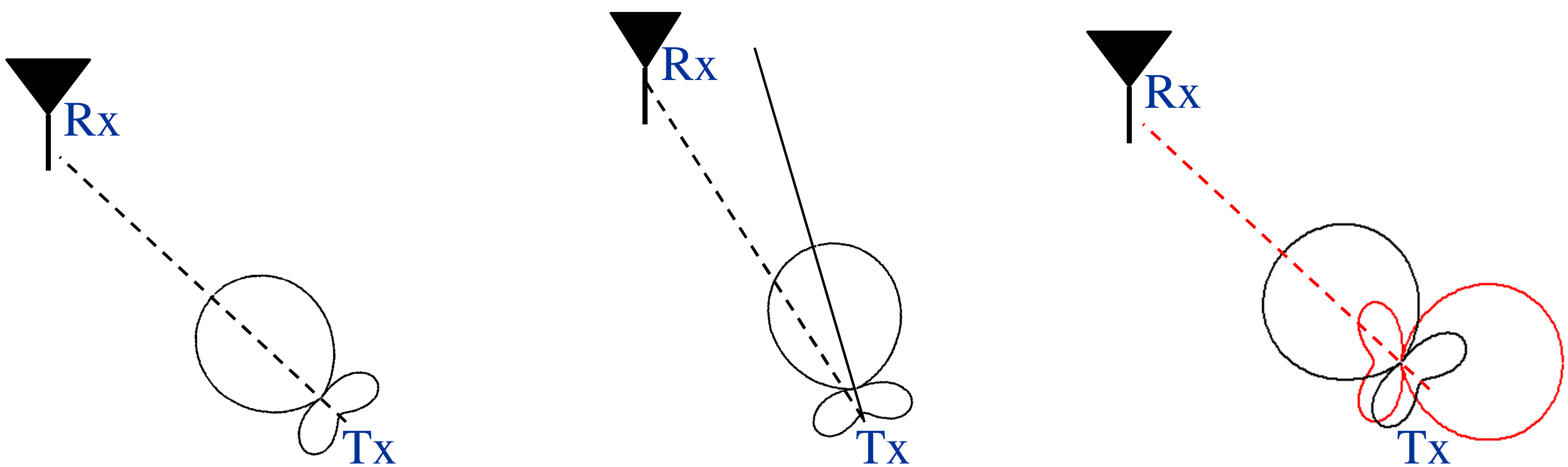




Effect of Antenna Pattern on Ranging Results

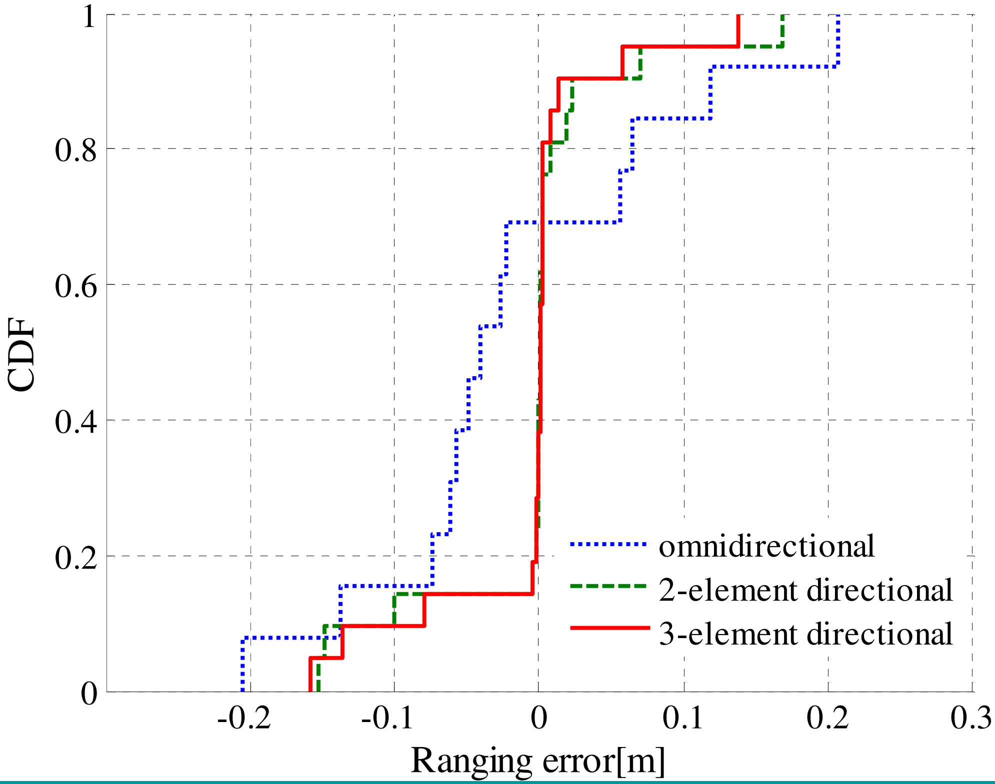
Repeating the ranging analysis with directional Tx antennas (using the virtual array principle)

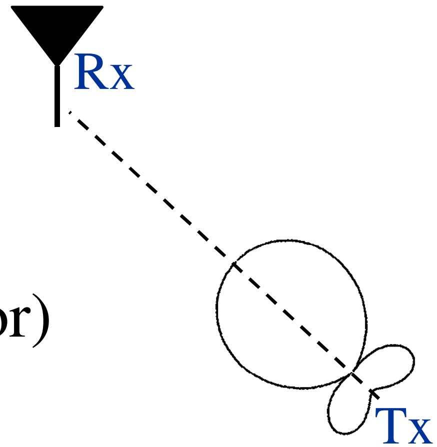
- Tx antenna point to the Rx
- Tx antenna point to the random direction
- Rotating Tx antenna; relative directivity effect on ranging



Tx antenna point to the Rx

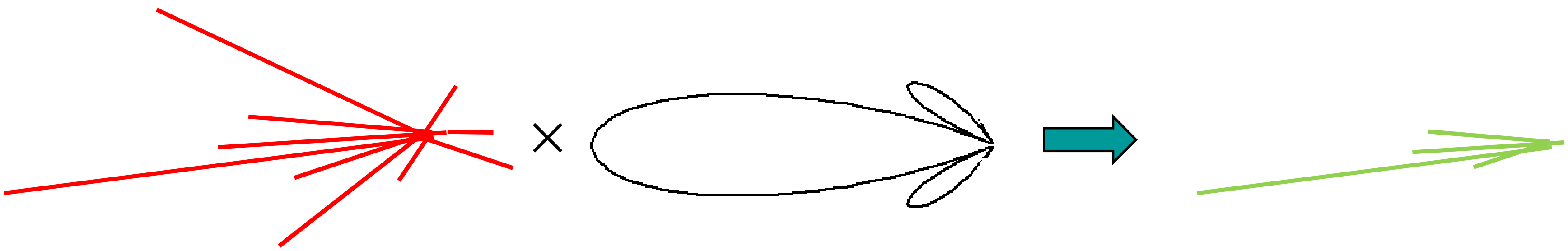
- In omni-directional case
  - greater variance
  - longer tail in CDF curve (greater maximum error)





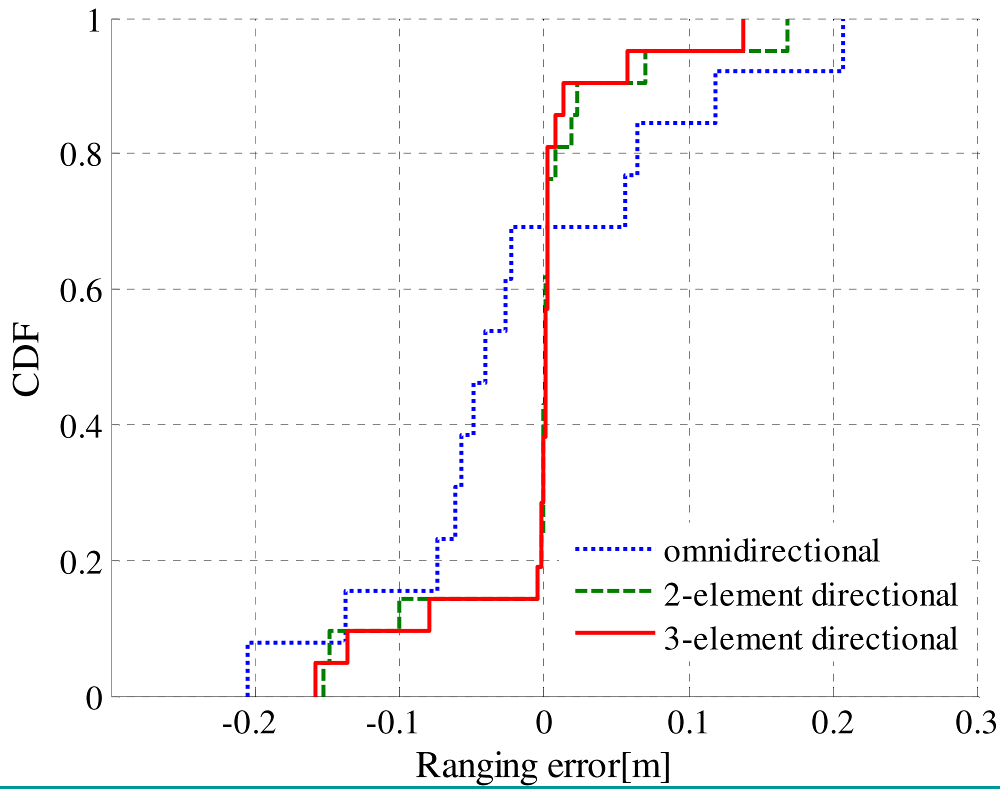
Directional antenna→reduction of error

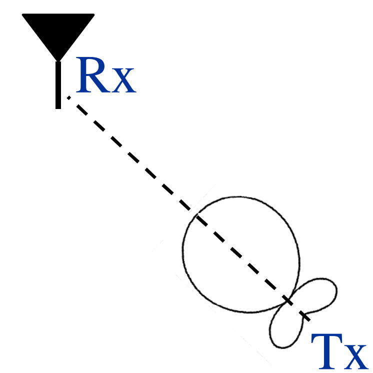
- transmitting power in only one direction →reduces number of scatterers & angular spread
- increases Ricean K factor →increase probability of direct path being dominant path →reducing missed path errors
- greater delay between first and second multipaths →some of the paths in between no longer exist→facilitates detection of direct path



Small ranging errors are still observed!

- Enhancement of closely spaced multipath components → surrounding multipath components cross the threshold → challenging ToA estimation





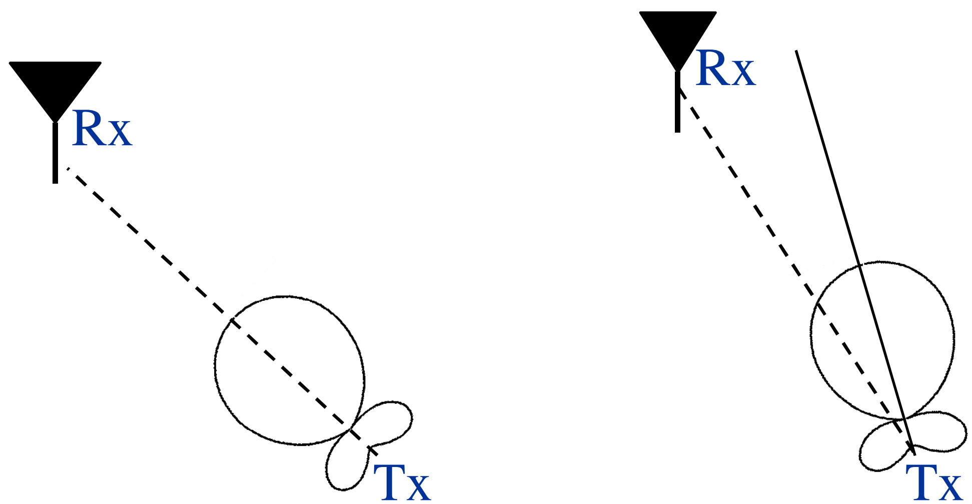
Non-proper use of directive antenna

Properly use of a directive antenna ≡ Tx antenna beam point at the Rx

Problems with antenna orientation →may degrade ranging performance

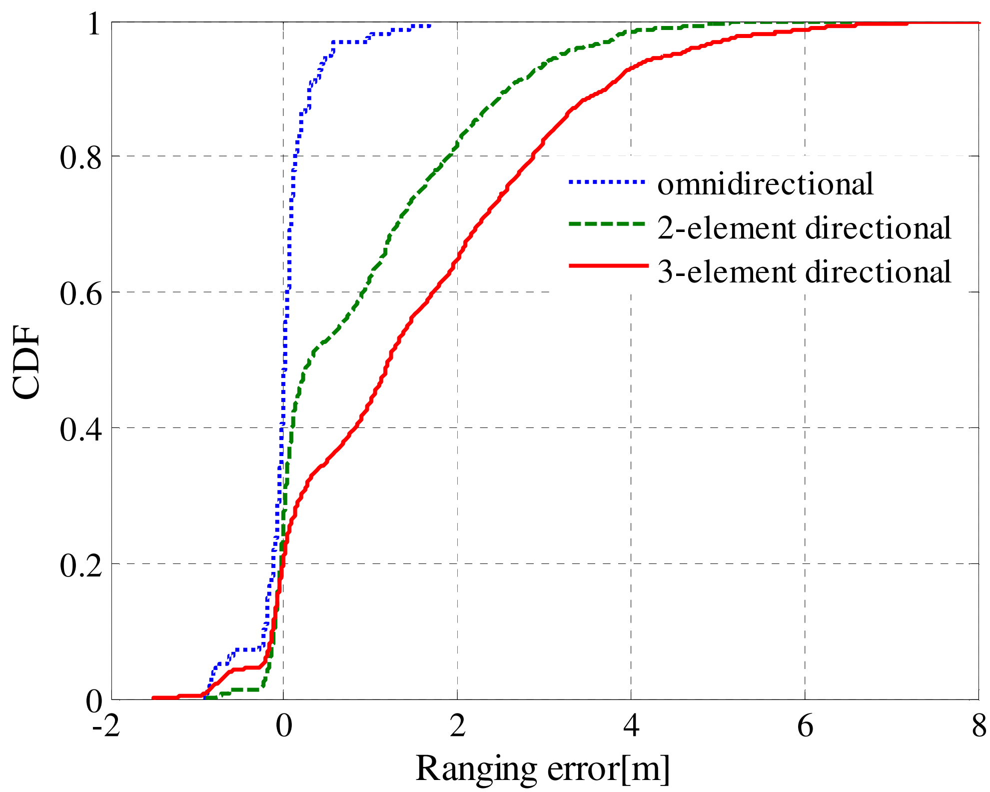
Investigate the effect of non-proper use of directive antenna

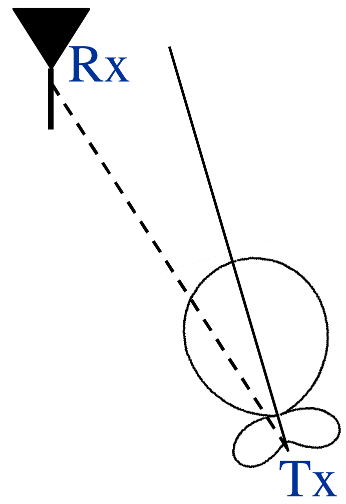
- Main-beam points to any arbitrary direction including direction of Rx
- Probability of pointing to true direction same as all the other directions



Tx antenna point to the random direction

non-proper use of directive antenna ≡ beam may point to wrong direction
→ missing the signal power → degrades ranging performance





Tx antenna point to the random direction

- signal comes from a side lobe direction → small received signal
- null of antenna beam points at Rx → missing the signal power→ largest ranging errors

- ✓ noise & multipath enhancement→ detection of noise as a multipath →negative errors (early false alarm)
- ✓ multipath components (after the DP) enhancement →large positive errors (miss the DP)

- ❖ directive antenna with larger beam width →more opportunity to observe the Rx→ better performance

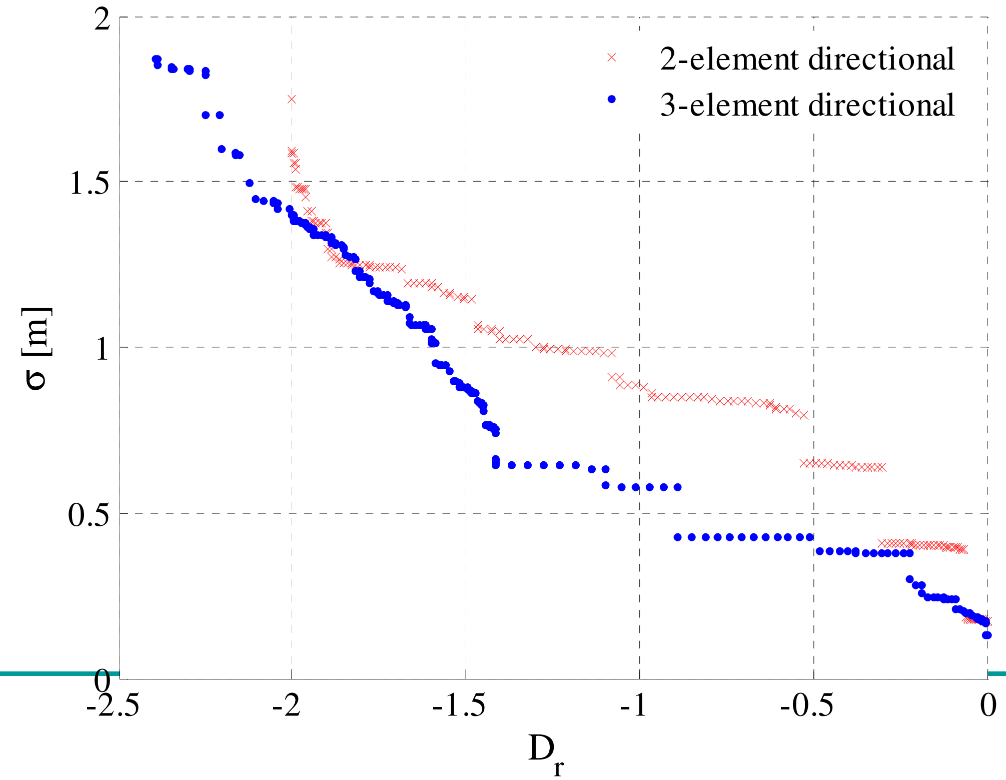
Rotating the Tx antenna

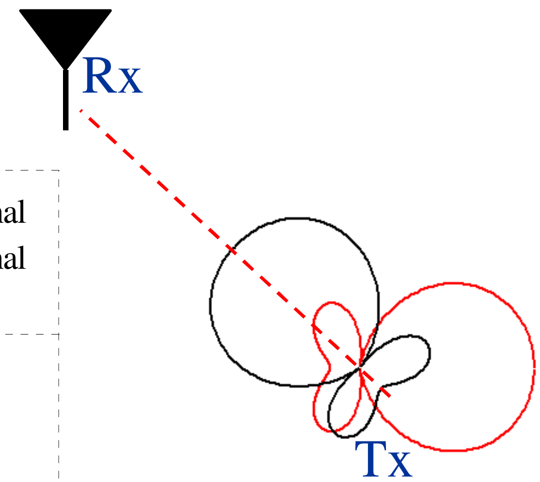
→ deviation of main beam from the direction of Rx

→directivity in direction of LoS varies

Relative directivity ≡ antenna gain in the direction of LoS relative to the main lobe antenna gain

$$D_{\mathrm{r}} = \frac{D_{\mathrm{LoS}}}{D_{\max}}$$





Summary

Two types of ranging errors in dense multipath environment

- missed path errors
- early false alarm errors

Properly oriented directional antenna→reduction of number of received multipaths → increase probability of DP being dominant path → standard deviation of errors decreases