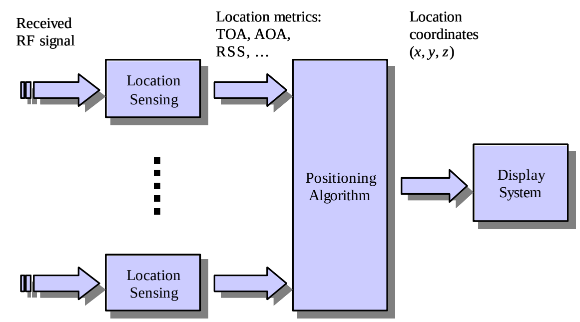
Indoor Geolocation Applications

- Positioning and tracking applications
  - Commercial: finding in-demand equipments, in-need personnel, such as elderly, children and patience, …
  - Military and public safety: positioning and guiding soldiers, firefighters in mission, …
- Location-aided techniques
  - Location-aware routing, location-aided handoff, location-aided network planning, …
- Location-based services
  - Location sensitive billing, location aware services, location specific advertisement, …

Wireless Geolocation Systems



Multipath Indoor Radio Channel

- Channel characteristics:
  - site-specific, severe multipath, low probabilities of LOS
- Two major sources of errors in location sensing:
  - multipath fading and no-LOS
- Multipath channel model:

$$h(t) = \sum_{k=0}^{L_p-1} a_k \delta(t - \tau_k)$$

MUSIC for TOA Estimation (1/2)

$$H(f) = \sum_{k=0}^{L_p-1} a_k e^{-j2\pi f \tau_k}$$

$$x(l) = H(f_l) + w(l), \quad \text{for} \quad l = 0, 1, \ldots, L-1$$

$$\mathbf{x} = \mathbf{V}\,\mathbf{a} + \mathbf{w} = [\mathbf{v}(\tau_0) \quad \ldots \quad \mathbf{v}(\tau_{L_p-1})]\,\mathbf{a} + \mathbf{w}$$

$$\mathbf{a} = [a_0 e^{-j2\pi f_0 \tau_0} \quad \ldots \quad a_{L_p-1} e^{-j2\pi f_0 \tau_{L_p-1}}]^T$$

$$\mathbf{v}(\tau_k) = [1 \quad e^{-j2\pi\Delta f \tau_k} \quad \ldots \quad e^{-j2\pi(L-1)\Delta f \tau_k}]^T$$

$$\mathbf{w} = [w(0) \quad \ldots \quad w(L-1)]^T$$

$$\mathbf{R}_{xx} = E\{\mathbf{x}\,\mathbf{x}^H\} = \mathbf{VAV}^H + \sigma_w^2 \mathbf{I}$$

$$\mathbf{A} = diag\{|a_0|^2 \quad \ldots \quad |a_{L_p-1}|^2\}$$

MUSIC for TOA Estimation (2/2)

$$\mathbf{R}_{xx} = \mathbf{VAV}^{H} + s_w^2\mathbf{I}$$
$$= \sum_{l=0}^{L-1} l_l \mathbf{q}_l \mathbf{q}_l^H$$
$$= \sum_{l=0}^{L_p-1} (l_l' + s_w^2)\mathbf{q}_l\mathbf{q}_l^H + \sum_{l=L_p}^{L-1} s_w^2 \mathbf{q}_l\mathbf{q}_l^H$$
$$= \mathbf{Q}_s \Lambda_s \mathbf{Q}_s^H + s_w^2 \mathbf{Q}_w \mathbf{Q}_w^H$$

$$\mathbf{P}_w = \mathbf{Q}_w(\mathbf{Q}_w^H\mathbf{Q}_w)^{-1}\mathbf{Q}_w^H = \mathbf{Q}_w\mathbf{Q}_w^H$$

$$\mathbf{P}_w \mathbf{v}(t_k) = \mathbf{0}$$

$$S_{music}(t) = \frac{1}{\|\mathbf{P}_w \mathbf{v}(t)\|^2} = \frac{1}{\|\mathbf{Q}_w^H \mathbf{v}(t)\|^2}$$

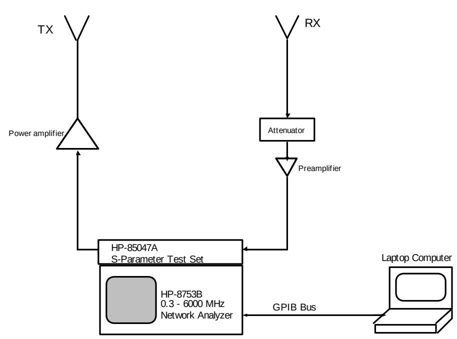
$$\hat{\mathbf{R}}_{xx} = \frac{1}{N}\mathbf{X}^H\mathbf{X}$$

$$\mathbf{X} = \begin{bmatrix} \mathbf{x}^T(0) \\ \vdots \\ \mathbf{x}^T(N-1) \end{bmatrix} = \begin{bmatrix} x(0) & \cdots & x(L-1) \\ \vdots & \ddots & \vdots \\ x(N-1) & \cdots & x(N+L-2) \end{bmatrix}$$

Some Considerations in Practical Implementation

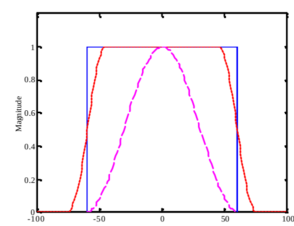
- Optimum value of *L*
- Improve the estimation of Rxx
- Optimum value of *Lp*
- Improve performance when eigen-values of noise subspace are not equal

Channel Measurement System

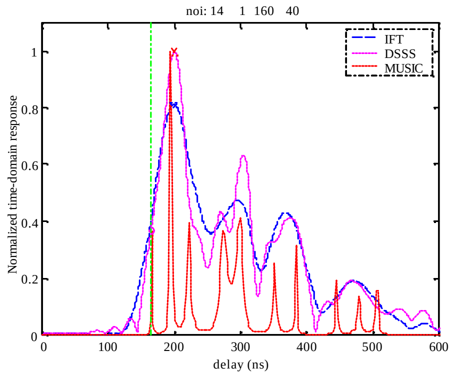


Simulation Over Measurement Data

- Super-resolution Technique
- Cross-correlation technique using DSSS signal
- Inverse Fourier transform



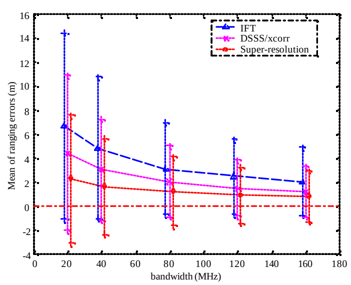
Sample Channel Delay Profile

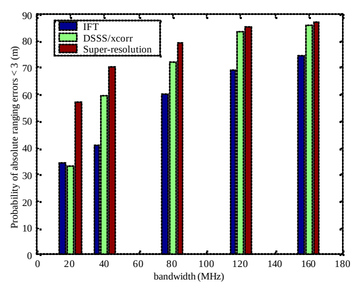


Measurement Sites and Scenarios

- Sites:
  - Manufacturing building
  - Modern office building
  - Residential building
- Scenarios:
  - Indoor-to-indoor
  - Outdoor-to-indoor
  - Outdoor-to-second floor

Sample Statistical Results





Conclusions

- Super-resolution subspace techniques can be used for TOA estimation in frequency domain.
- Performance over measurement data shows that super-resolution technique can improve the accuracy of TOA estimation when compared to conventional techniques.
- Super-resolution technique is preferred especially when channel bandwidth is small.