Mobile Localization

- Safety
  - Wireless E911 (FCC mandate by 2001)
  - Emergency roadside service

- Tracking
  - Fleet management for trucks
  - Tracking children

- Billing
  - Location sensitive billing
  - Neighborhood cordless

- Information
  - Mobile yellow pages
  - Driving directions
System Requirements

- Mobile user requests its location
- Infrastructure-based solution
  - Support existing mobile phones
  - No additional cost to mobile phones
- Compatibility with different standards
  - Advanced Mobile Phone Service (AMPS)
  - Code Division Multiple Access (CDMA)
  - Global System for Mobile (GSM)
- Solutions at base station
  - Single antenna
  - Antenna array (usually linear but sometimes triangular or circular)
Location Based on Direction of Arrival (DOA)

Two-site visibility
Direction of Arrival Estimation

- **Sampling in space**
- Narrowband
- Delay $\Rightarrow$ Phase Shift
- Assumption

$$a(\theta) = \begin{bmatrix} 1 & e^{j2\pi f \frac{d}{c} \sin \theta} & \cdots & e^{j2\pi f \frac{4d}{c} \sin \theta} \end{bmatrix}^T$$

For $P$ paths,

$$A = [a(\theta_1) \ a(\theta_2) \ \cdots \ a(\theta_P)]$$

$A$ is a Vandermonde matrix

- **Estimate $\theta_i$ using Estimation of Signal Parameters using Rotationl Invariance Techniques (ESPRIT)**
Disadvantages of Using Direction of Arrival

- Few antenna elements at basestation (usually 4)
- Extremely sensitive to array calibration
  - Geometry of sensor layout
  - Mutual coupling of antenna elements
- No line-of-sight in urban environments
- Failure in absence of fading
Location Based on Time of Arrival (TOA)

Three-site visibility required
Time of Arrival Estimation

- Received signal $\rightarrow$ Sum of delayed versions of transmitted signal

$$S(t) = [s(t - \tau_1) \ s(t - \tau_2) \ s(t - \tau_3) \ \ldots \ s(t - \tau_P)]^T$$

- Delay $\tau_m$ $\rightarrow$ Phase Shift $e^{j2\pi f \tau_m}$

- Fourier Transform

$$\hat{S} = [e^{j2\pi f \tau_1} \ e^{j2\pi f \tau_2} \ \ldots \ e^{j2\pi f \tau_P}]^T \ \hat{s}(f)$$

where $\hat{s}(f) = \mathcal{F}\{s(t)\}$

- Estimate time delays $\{\tau_i\}$ using ESPRIT
Location Based on
Time Difference of Arrival (TDOA)

TDOA hyperbola

Three-site visibility required
Location Based on a Combination of DOA and TOA

Single-site visibility (35-40% of the cases)
Joint Angle and Delay Estimation (JADE)

- 1-D ESPRIT
  - Sequential estimation of DOAs and TOAs
  - Classification problem

- JADE - ESPRIT
  - Joint estimation of DOAs and TOAs
  - Automatic pairing of DOAs and TOAs for each user

- Form a 2-D Vandermonde matrix
  - Angle-of-arrival along columns
  - Time-of-arrival along rows

- Large number of time samples $\rightarrow$ better accuracy

- Works in both fading and non-fading environment
Simulation Results

Root mean square TOA error vs. SNR at the basestation
Simulation Results

Root mean square DOA error vs. SNR at the base station