Mobile Phone Location

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Mobile Location Applications

Applications once know location:

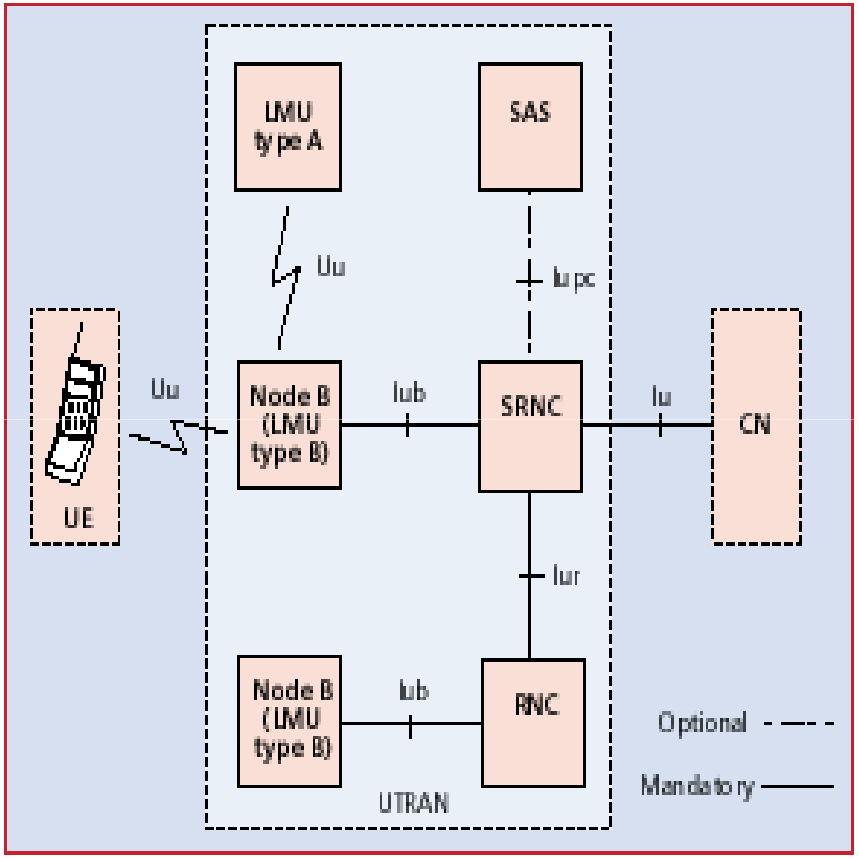
- What is around me (shops, sites, etc)?
- Where are my friends, family, employees?
- How to get there (travel directions)?
- Who can help me (emergencies, questions)?
- Change cost for voice and data transfer?

Currently Available Applications

- Smart, Data Mobile Phones (Google, I-Phone, Blackberry Storm)
- Emergency Mobile Phone Service (Voice, Smart, Data phones)

Location: System Architecture

- UE – User Equipment
  (i.e., Mobile Phone)
- Node B - Base Station or Tower
- SRNC - Serving Radio Network Controller
- LMU - Location Measurement Unit (Type A Standalone;
  Type B with Base Station)
- SAS – Stand-Alone SMLC (Serving Mobile Location Center)
- CN - Core Network



Reference: Zaho 2002

Method: Mobile Tower

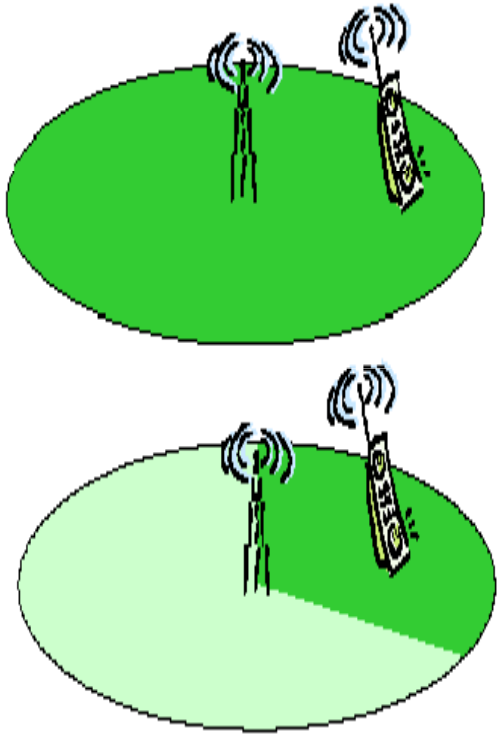
Tower (cell) only Location

- Estimates location (position) via Mobile Tower that communicates with the Mobile Phone

Tower Sector Location

- Tower Sector (Antenna Facing direction) that communicates with the Mobile Phone

Simplest solution, normally default location.

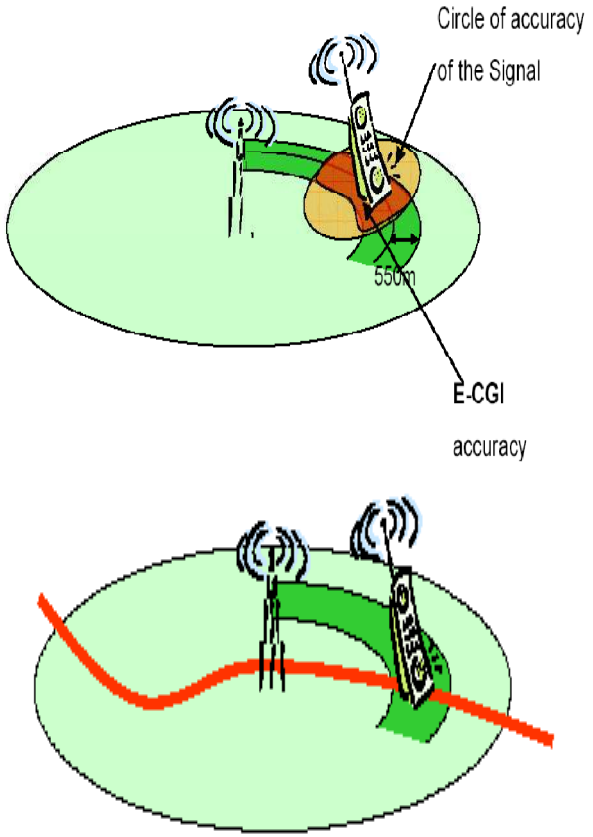


Reference: Raja 2003

Method: Timing Advance

Tower - Timing Advance

- Extends Tower only or Tower Sector solution with uniform timing ring distances based on signal or arrival calculations.
- Example 300 meters per micro-second arrival time.
- Also can be used with other method when have less than required LMU to calculate position



Reference: Raja 2003

Method: AoA

Angle of Arrival

- Tri-Angulation method using the Mobile Phone's Radio Frequency (RF) arrival angle direction with Mobile Tower (directional antennas or antenna arrays).
- The intersection of two directional bearing lines determine a unique 2-Dimentional position. (see Figure AoA)
- It is costly to produce Mobile Towers or other RF equipment with these special antennas.
- Only Tower Equipment implementation.
- Usable with any Mobile Phone (data, voice, smart, feature)

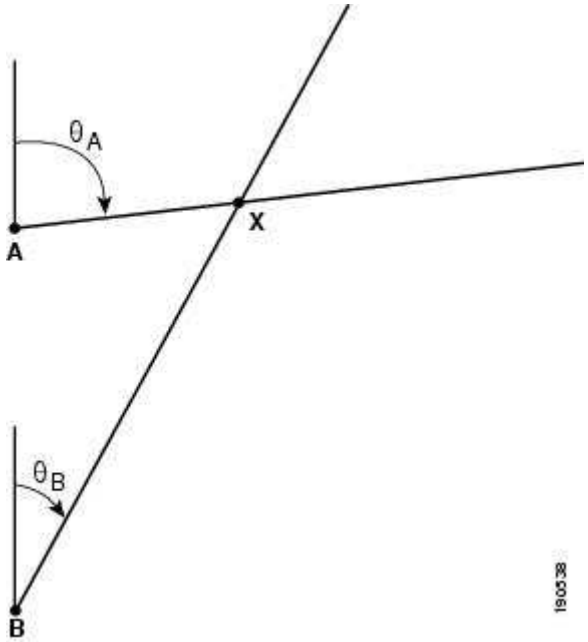
Reference: Zaho 2002

Figure: AoA

AoA Calculations

Mobile phone X and receiving towers A and B with angle directional antennas adjusted to the point of highest signal strength to measure the angles of incidence θ_A and θ_B respectively.

AoA uses include military, aircraft navigation, law enforcement, and traveling equipment.



Reference: Cisco 2008

Method: ToA

Time of Arrival

- Tri-Lateration method using the intersection of the distance circles based on the Mobile Phone's echo arrival time with Mobile Towers.
- Multiplying arrival time by the speed of light obtains the Mobile Phone's range from Tower.
- Three distance measurements determine a unique 2-Dimentional position. (see Figure: ToA)
- It is economical to produce Mobile Towers with arrival time calculations.
- Only Tower Equipment implementation.

Reference: Zaho 2002

Figure: ToA

ToA Calculations

D = c (t) where:

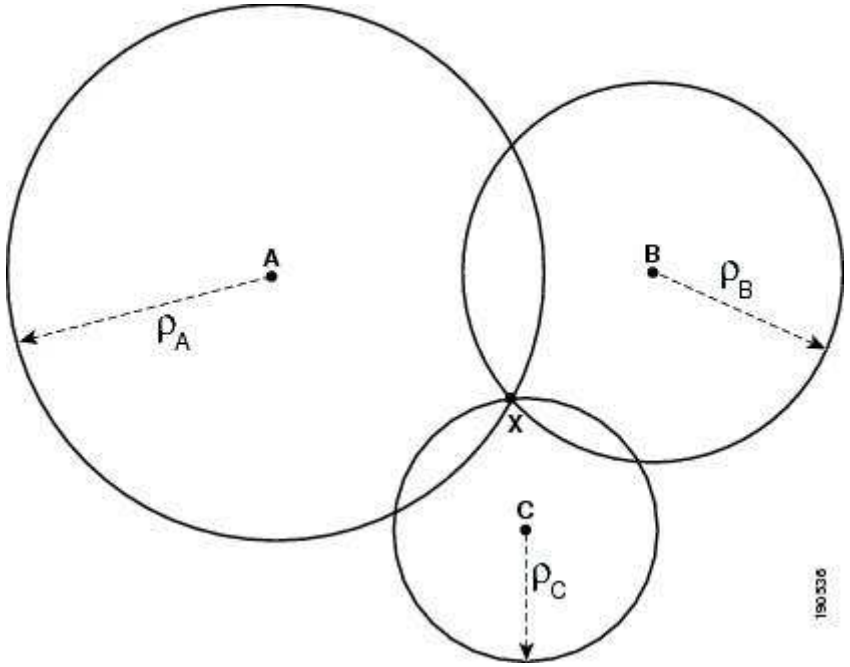
D = distance (meters)

c = propagation speed about 300 meters / microsecond

t = time in microseconds

Mobile Phone X signal arrive at towers A, B, and C precisely measured as t_A, t_B, and t_C

Calculated tower distances as ρ_A, ρ_B, and ρ_C, respectively



Reference: Cisco 2008

Method: TDoA

Time Difference of Arrival

- Tri-Lateration method using time difference measurements rather than the TOA absolute time measurements.
- The time differences is converted to a constant distance difference with two Mobile Towers (as foci) to define a hyperbolic curve.
- The intersection of two hyperbolas determines a unique 2-Dimentional position. (see Figure TDoA)
- Need at least three Mobile Towers to generate the two hyperbolas. (A to B; and A to C)
- TDoA accuracy requires either precisely synchronized clocks for all transmitters and receivers or a means to measure these time differences.
- Only Tower Equipment implementation.

Reference: Zaho 2002

Figure: TDoA

TDoA Calculations

Mobile Phone X signal arrives at Tower A with time T_B, at Tower B with time T_B and at Tower C with time T_B.

TDoA calculated between Towers A and B as the positive constant k_1,

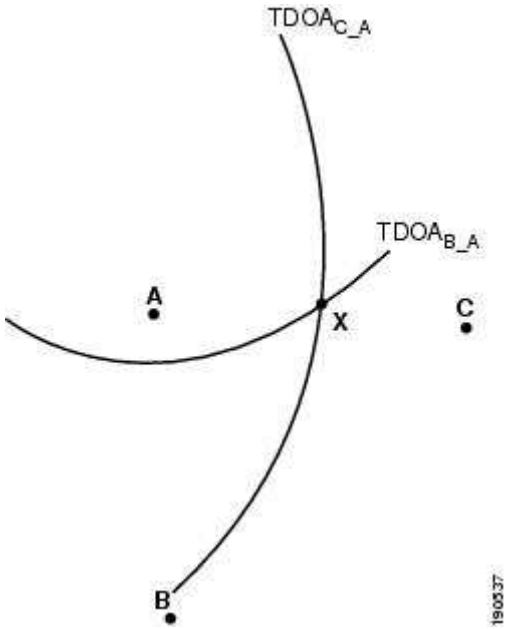
Where: $TDoA_{A-B} = | T_A - T_B | = k_1$

Creates the hyperbola $| D_{XA} - D_{XB} | = k_1$ (c)

TDoA calculated between Towers A and C as the positive constant k_2,

Where: $TDoA_{A-C} = | T_A - T_C | = k_2$

Creates the hyperbola $| D_{XA} - D_{XC} | = k_2$ (c)



Reference: Cisco 2008

Implementation: TDOA

Uplink - Time Difference of Arrival

- TruePosition TDOA implementation at 65,000 U.S. Towers with Location Measurement Unit (LMU) equipment to determine Mobile Phone location within 50 meters in less than 10 seconds.
- Typical location accuracy uses at least 8 and up to 50 LMU.
- Implementation Concerns:
  - Signal-to-Noise Ratio: radio interference present. Less is better
  - Integration Time: longer signal timer better statistical processing
  - Signal Bandwidth: higher bandwidth has more energy to capture
  - Super-Resolution: multi-paths via object bouncing (buildings)
  - Receiver Timing Stability: more precise the better
  - Receiver-Transmitter Geometry: distribution of towers around the mobile
  - Number of Measurements: more Tower (LMU) the better

Reference: TruePosition 2008

Method: GPS

Global Positioning System

- Similar to Time of Arrival (ToA) triangulation method using at least four satellite distance measurements for a 3-Dimentional position
  - Measuring distance from the satellites to the receiver by determining the pseudo-ranges
  - Extracting satellite transmitted ToA pseudo-ranges
  - Computing reference satellites 3-Dimentional position (X, Y, Z)
  - Calculating Mobile Phone position via satellites position, clock bias and ToA pseudo-ranges
- Mobile Phone location within 10 Meter accuracy
- Only Mobile Phone Equipment and GPS satellites

Reference: Zaho 2002

Problems: GPS

GPS issues

- Relatively long startup time (between 30 seconds and few minutes) compare to Tower ToA, TDoA methods. Because navigation messages have long acquisition time.
- Unable to detect weak signals via indoor, urban canyon and small Mobile Phone antennas.
- Mobile Phone high power usage per position
  - Long signal acquisition time to determine position
  - Signal strength to reach satellites
- Mobile Network providers want your location

Reference: Zaho 2002

Method: Assisted GPS

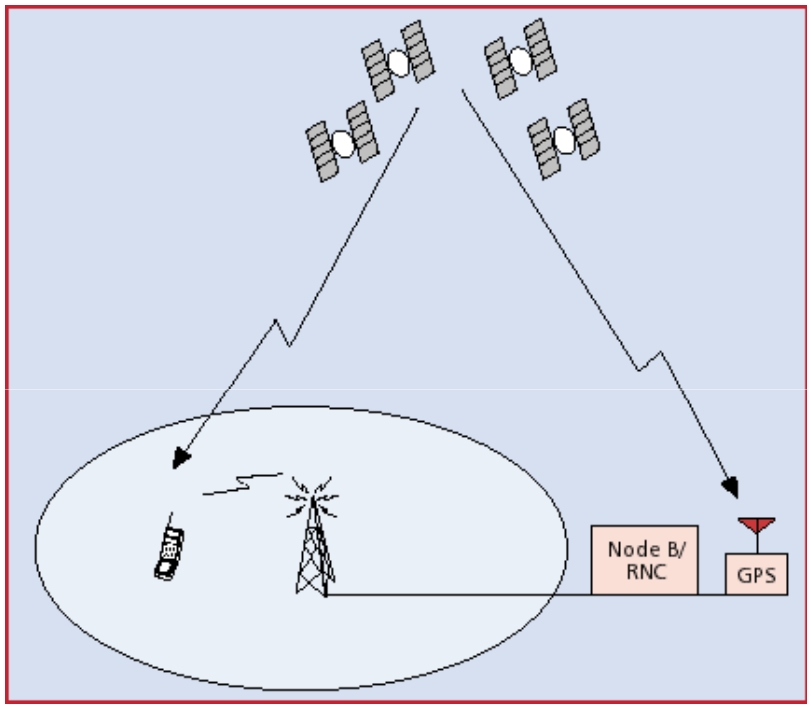
Assisted Global Positioning System

- GPS reference network connected to Mobile Phone system
  - Continuously monitors the real-time satellite status and locations
  - Calculates approximate mobile phone position, satellite visibility, and clock corrections
- Mobile phone upon requests, receives reference network calculations which
  - Decreases startup time via satellite references and locations.
  - Decreases acquisition time via predicting the search space and narrower signal search bandwidth.
  - Reduces mobile phone power usage per location
- Mobile Phone location within 30 meter accuracy

Reference: Zaho 2002

Figure: Assisted GPS

- UE – User Equipment (Mobile Phone)
- Mobile System Tower
- Node B - Base Station with Radio Network Controller (RNC)
- GPS reference network



Reference: Zaho 2002

Location: RF Fingerprinting

Radio Frequency Fingerprinting

Location pattern method based on the sampling and recording of radio frequency signal behavior patterns in specific environments (coverage area)

Mostly software calculations or algorithms using signal strength and maybe other methods like Timing Advance, AoA, ToA

Location pattern methods assume:

- Each potential device location ideally possesses a distinctly unique RF signature
- Each coverage area possesses unique signal propagation characteristics.

Deployment: Calibration and Operational phases

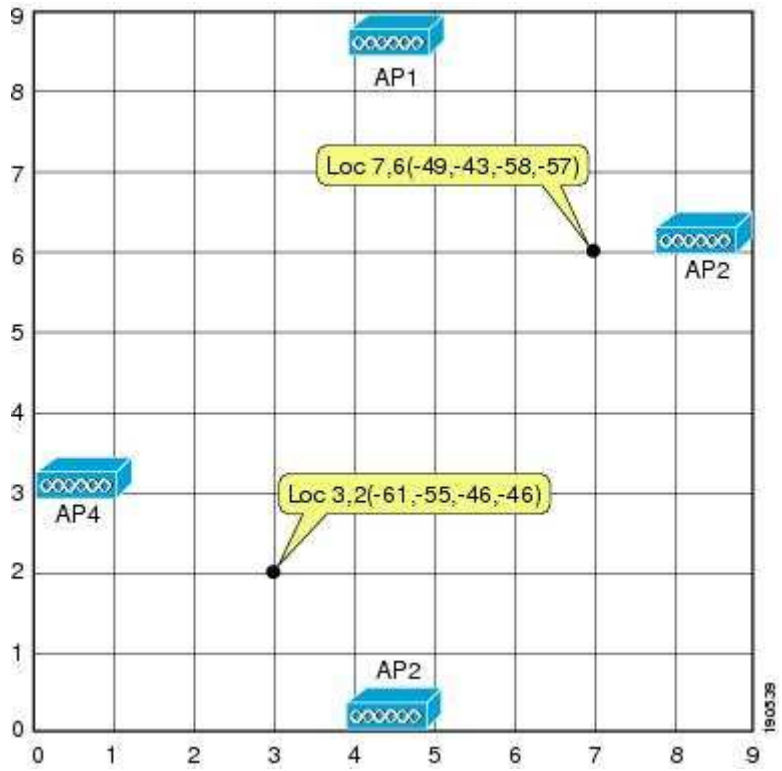
Reference: Cisco 2008

Calibration: RF Fingerprinting

Overlay coverage area with grid points to determining sample data locations.

At each sample location, record the signal strength location vector values associated with the calibration device into the as a radio map (training) database

Since mobile phone signal strength vary over time, need to records many mobile phone signal strength samples at each sample location



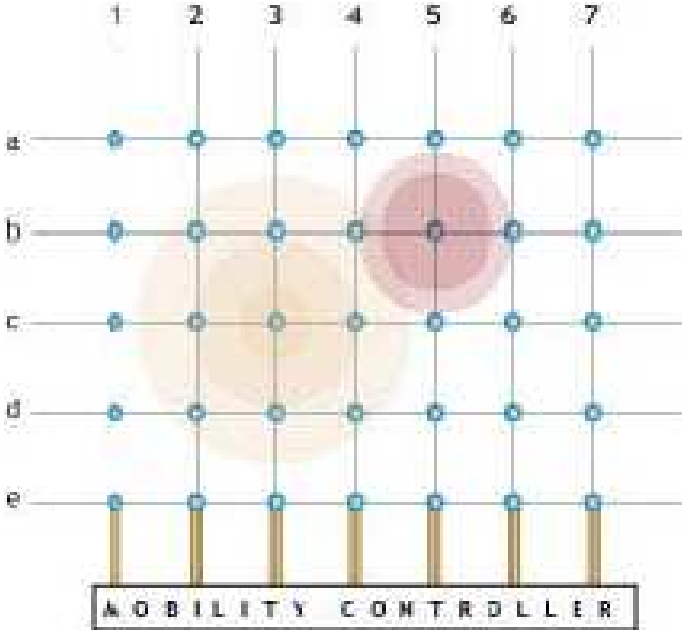
Reference: Cisco 2008

Operational: RF Fingerprinting

Deterministic algorithms:
- minimum statistical signal distance between a detected signal and calibrated location vectors (Euclidean distance)

Probabilistic algorithms:
- inferences likelihood particular location given its location vector array is already calibrated (Bayesian)

Other techniques: Non-linear
- discriminant functions,
- Neural networks and
- Machine learning



Reference: Cisco 2008 and Thornycroft

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