S-72.333 Postgraduate Course in Radio Communications

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WLAN Location Methods

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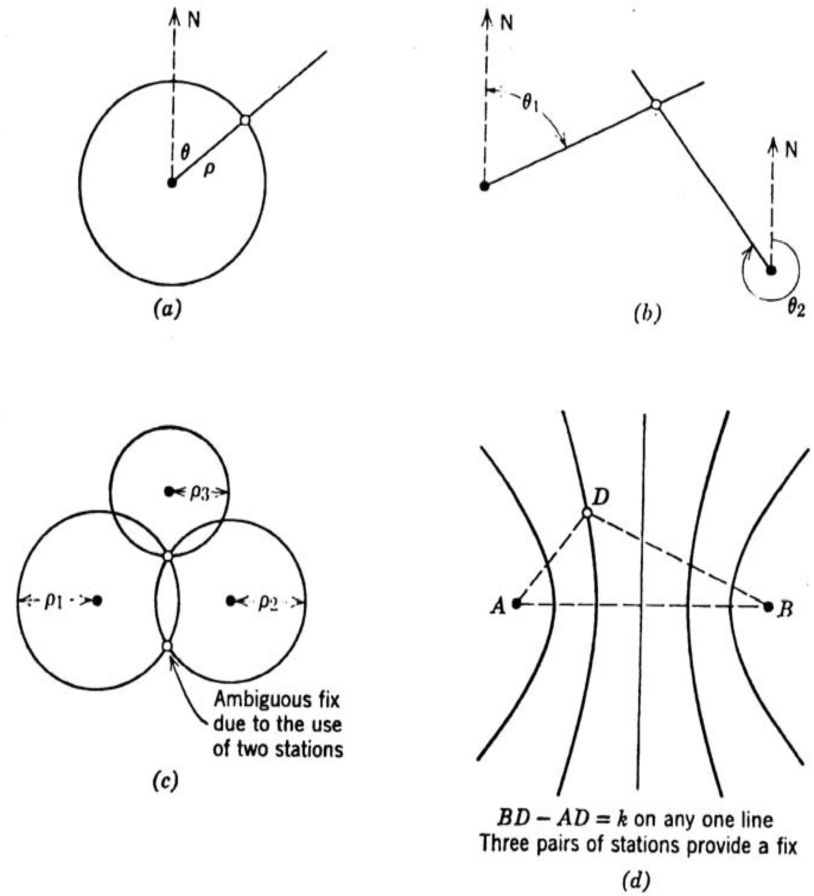
Contents

- Overview of Radiolocation
- Radiolocation in IEEE 802.11
    - Signal strength based methods
    - Accuracy analysis
- Differential Time of Arrival (UWB)
- Location based services and applications

Conventional Radiolocation Methods

- Measurements such as
  - Time of Arrival (ToA)
  - Amplitude
  - Phase
  - Angle of Arrival (AoA)

  are related to the geometry of TX and RX locations
- Possible geometries: (a) $\rho-\theta$ (b) $\theta-\theta$, (c) $\rho-\rho$, (d) hyperbolic
- Location accuracy depends on propagation effects, measurement accuracy and geometry



Radiolocation Systems

- Dedicated location/navigation systems
  - Satellite systems (GPS, Glonass, Galileo)
  - Terrestrial systems
    - Air navigation (NDB, VOR, DME, ILS, MLS, ...)
    - Maritime navigation (Loran-C)
  - In-building RF, IR and ultrasonic systems

- Wireless communication systems
  - GSM
  - UMTS
  - WLANs (IEEE 802.11, UWB)

IEEE 802.11 Measurements for Location Determination

- WLAN location could be based on
  - ToA measurements
  - Signal strength measurements
- ToA techniques require very accurate clocks and synchronization
  => not applicable to IEEE 802.11
- Received Signal Strength Indication (RSSI) in 802.11 is a measure of received RF energy (8-bit value 0…RSSI Max)
  => applicable for location determination if constant or known TX power
- Signal strength can be measured from beacon packets that each AP sends several times per second
- Using RSSI enables software based solution to WLAN location

Indoor Propagation

- Severe multipath propagation
- Low probability of line-of-sight
- Effect of
  - floors
  - walls
  - corridors (waveguide effect)
- Random variations of signal strength due to
  - antenna orientation
  - user's body and other people
  - measurement inaccuracies

Received Signal Strength Models

- Log-distance model

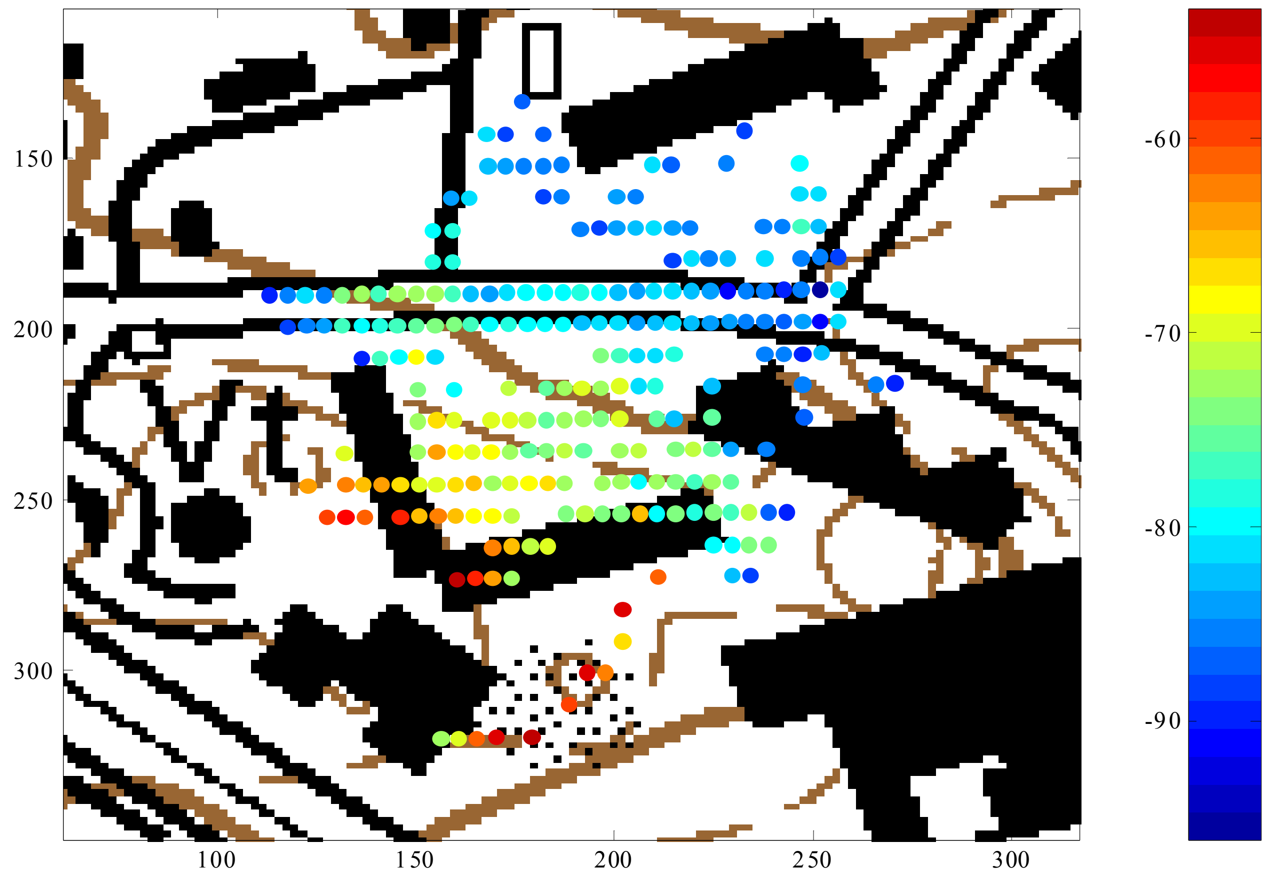
$$P(d)[dBm] = P(d_0)[dBm] - 10n\log\left(\frac{d}{d_0}\right)$$

- Wall Attenuation Factor (WAF) model

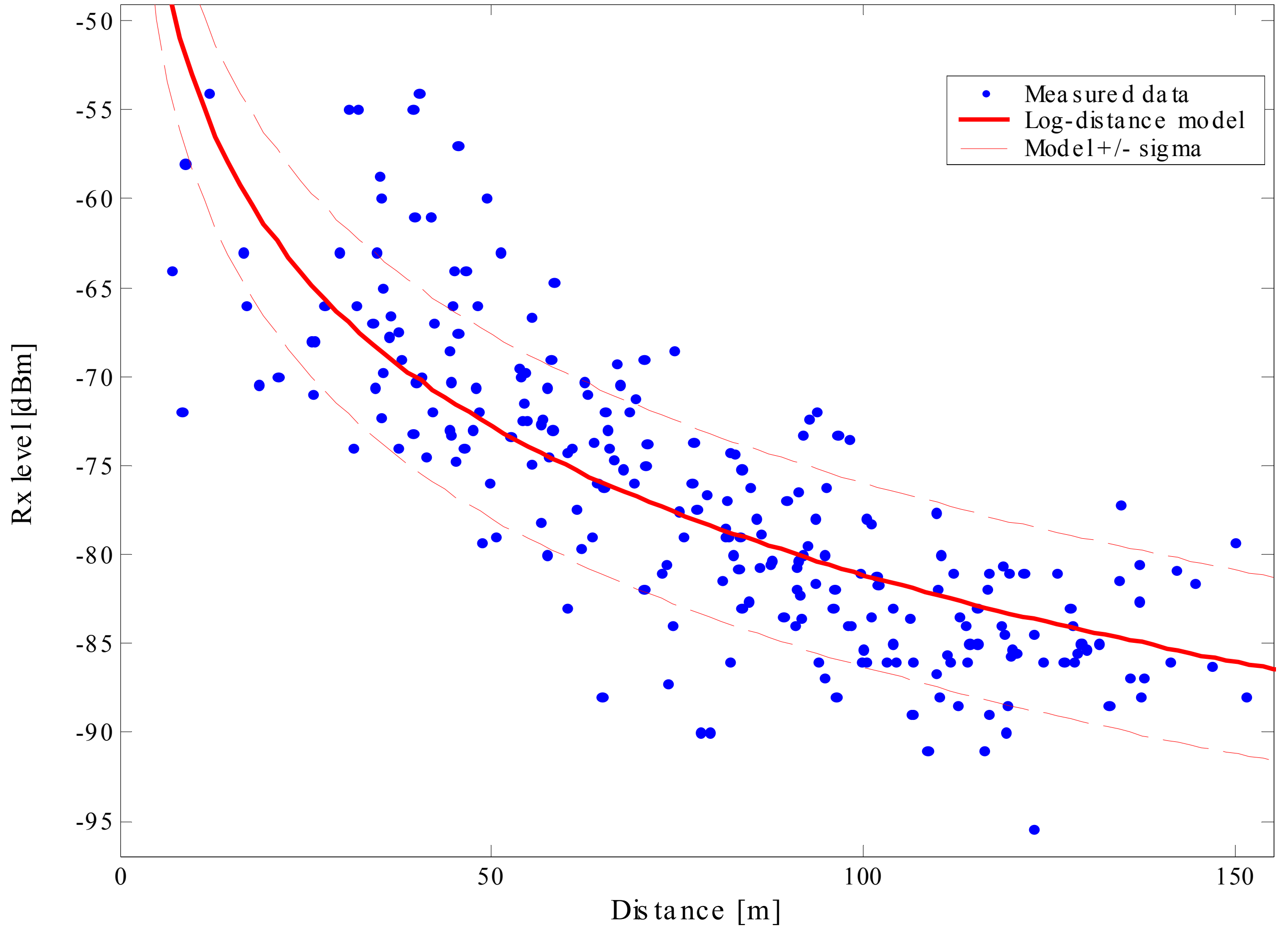
$$P(d)[dBm] = P(d_0)[dBm] - 10n\log\left(\frac{d}{d_0}\right) - \begin{cases} nW * WAF & nW < C \\ C * WAF & nW \geq C \end{cases}$$

  with empirically determined parameters n and WAF
- More detailed model of signal strength as a function of (x,y,z) based on
  - measured coverage maps
  - e.g. ray tracing modeling
- Random variations add an error term (typically assumed Gaussian)

Coverage Map



Log-distance Model vs Measurement



Location Algorithms

- Least squares algorithm finds a location estimate that gives minimum Euclidean distance between received signal strength and model
- It is maximum likelihood algorithm if error term is Gaussian
- Differentiating the log-distance model we obtain an estimate of location error covariance matrix and std [1]

n = path loss exponent

(x,y) = terminal location

(x_i,y_i) = location of AP_i

d_i = distance between terminal and AP_i

σ_p= std of signal power error term

σ_r= location error std

$$H = \frac{-10n}{\ln 10}\begin{bmatrix} \frac{x-x_1}{d_1^2} & \frac{y-y_1}{d_1^2} \\ \frac{x-x_2}{d_2^2} & \frac{y-y_2}{d_2^2} \\ \vdots & \vdots \\ \frac{x-x_N}{d_N^2} & \frac{y-y_N}{d_N^2} \end{bmatrix}$$

$$\mathrm{cov}(d\hat{r}) = \sigma_p^2 (H' H)^{-1} = \begin{bmatrix} \sigma_x^2 & \sigma_{xy}^2 \\ \sigma_{xy}^2 & \sigma_y^2 \end{bmatrix}$$

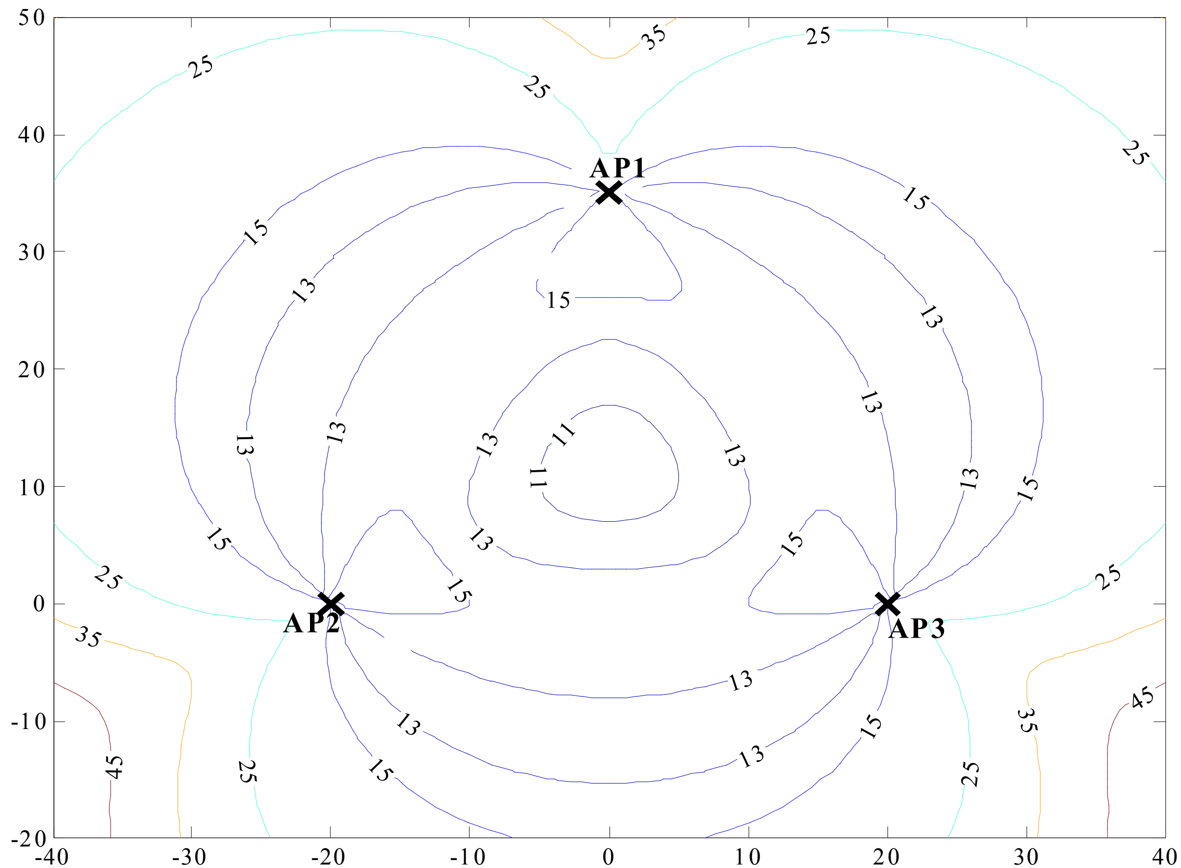
$$\sigma_r = \sqrt{\sigma_x^2 + \sigma_y^2}$$

Effect of Geometry and Distance

Contour plot of location accuracy estimate with 3 access points and

$$n = 3$$

$$\sigma_p = 5\,\mathrm{dB}$$



Other Factors Having an Effect on Accuracy

- Averaging over
  - space
  - time (packet duration, number of packets)
  - frequency
  - antenna orientation

  helps against multipath fading and shadowing
- Location grid density
- Mean value or distribution/histogram model
- Movement model
- Experimental results with median accuracies of 2-5 m [2] or better [3] using 3 APs have been reported

Ultra Wideband Location

- Using short RF pulses of extremely high bandwidth enables accurate ToA measurements with good multipath tolerance
- UWB communication and location technology has been under extensive research and development recently
- Benefits of UWB location [5]:
  - accurate timing measurements (nanosecond pulses, leading edge detection) even in multipath
  - low data rate => high peak power allowed => longer range than in UWB communications
  - low power consumption (long battery life)
- Demonstrated rms accuracy [4,5]
  - Better than 1 ft. in good conditions
  - Shipboard cargo holds: 3-5 ft. (open space) and 11-12 ft (blockage)

Precision Asset Location System [4,5]

- UWB receivers in known locations (at least 3, typically 4)
- Active UWB tags:
  - reference tag in known location
  - tags to be located
- Center frequency 6.2 GHz
- Bandwidth:
  - 400 MHz (-3 dB)
  - 1.25 GHz (-10 dB)
- ToA resolution 1 ns
- Range:
  - 600 ft. in LoS
  - 200 ft. indoors
- Expected battery life 3.8 yrs

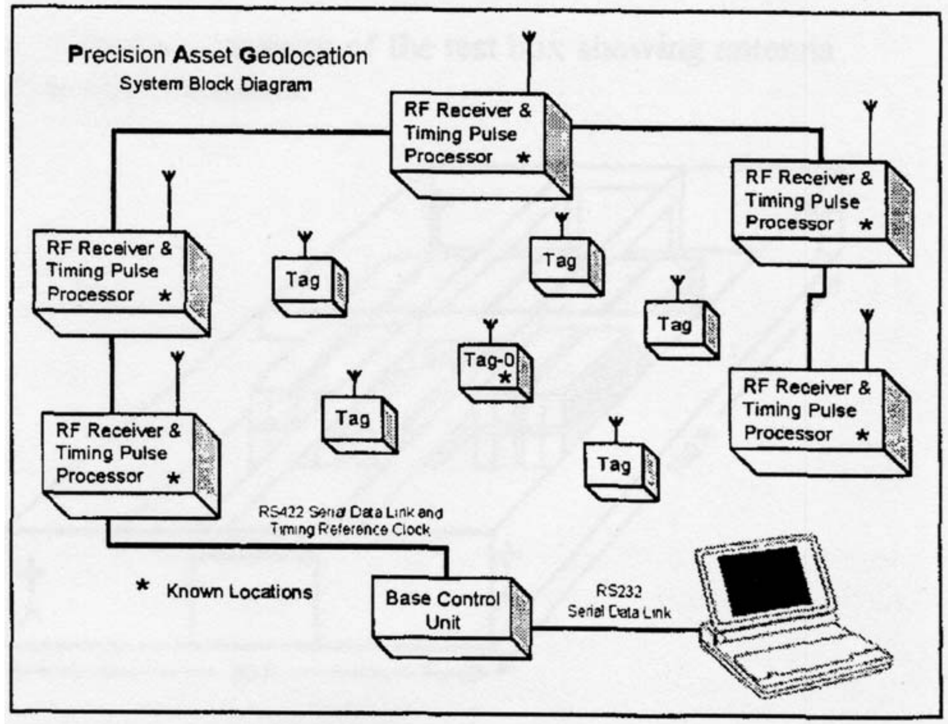


Figure 3. PAL System Architecture

Location Based Services and Applications

- Navigation aid for people as well as robots
- Shopping assistance and custormer behavior tracking
- Information services (nearby restaurants, movie show times etc.)
- Tracking of valuable assets in hospitals, factories and military facilities

- Accuracy requirements vary depending on application:
  e.g. print to the nearest printer vs find a product in a supermarket

Conclusion

- Indoor location technology based on WLAN signal strength has been developed and tested
- Accuracy on the order of office room size can be achieved
- UWB for applications requiring higher accuracy
- Commercial potential yet unclear

References

[1] Y. Chen, H. Kobayashi, “Signal strength based indoor geolocation,” IEEE International Conference on Communications, May 2002.

[2] P. Bahl and V. Padmanabhan, “RADAR: An In-Building RF-Based User Location and Tracking System,” IEEE INFOCOM, Israel, Mar. 2000.

[3] S. Saha, K. Chaudhuri, D. Sanghi, and P. Bhagwat, "Location Determination of a Mobile Device Using IEEE 802.11b Access Point Signals," pp. 1987-1992, 2003.

[4] R. J. Fontana and S. J. Gunderson, “Ultra-Wideband Precision Asset Location System," IEEE Conf. on Ultra Wideband Systems and Technologies, May 2002.

[5] R. J. Fontana, E. Richley, and J. Barney, “Commercialization of an Ultra Wideband Precision Asset Location System," IEEE Conf. on Ultra Wideband Systems and Technologies, Nov 2003.

Homework

Received signal power in dBm is modeled by

$$P(d) = -25 - 10n\log(d) + X_\sigma$$

where d is the distance between Tx and Rx, path loss exponent $n=3$, $\log$ is base 10 logarithm, and X_σ is Gaussian distributed random variable with standard deviation $\sigma = 5$ dB.

Having measured P, we can estimate the distance as

$$\hat{d} = 10^{(P+25)/(-10n)}$$

What is approximately the standard deviation of $\hat{d}$ when $d = 20\ m$ or $d = 100\ m$?