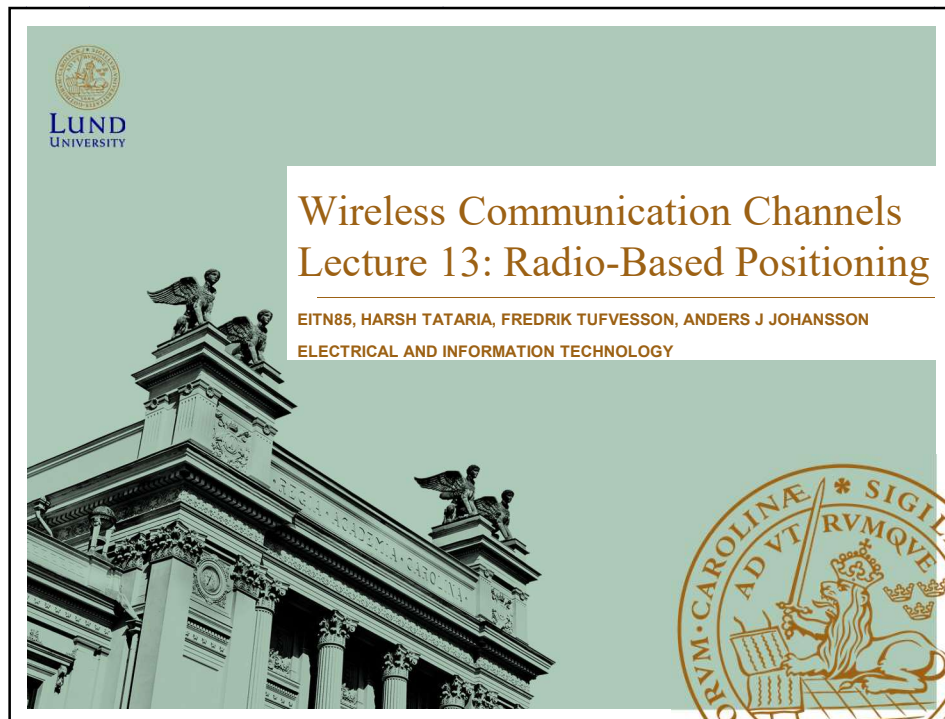




Overview

- Motivation: why wireless positioning?
- Core principles for wireless positioning
- Satellite positioning systems – GPS
- Summary

Why are we interested in wireless positioning?

Because there are a multitude of applications:

- **Network organization**, e.g., self-organizing sensor networks
- **Location-specific services**, e.g., billing, advertisement
- **Guiding** applications, e.g., augmented reality
- **Tracking** applications, e.g., players in sports
- **Automation and control**, e.g., forklifts in industry

To mention a few...

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Core principles for wireless positioning

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Self- and remote-positioning

Starting point: Several units with fixed positions and a **single mobile unit** with unknown coordinates

Self-(contained) positioning

- Fixed units transmit – **mobile unit measures**
- **Pros:** Works with existing wireless networks; integrity
- **Cons:** Accuracy limited by complexity of mobile unit

Remote positioning

- **Mobile unit transmit** – fixed units measure
- **Pros:** Mobile device can be small and cheap
- **Cons:** Requires backbone network; integrity

There are also indirect versions of both (position estimated at one side then shared with the other)

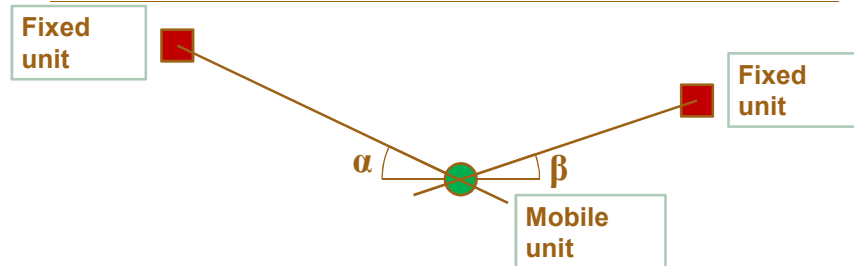
Techniques for wireless positioning

Three main measurement principles:

- Angle-of-arrival (AOA)
- Received signal strength (RSS)
- Propagation-time:
 - Time-of-arrival (TOA)
 - Roundtrip-time-of-flight (RTOF)
 - Time-difference-of-arrival (TDOA)

These differ both in terms of system requirements and in accuracy

Angle-of-arrival (AOA) based positioning



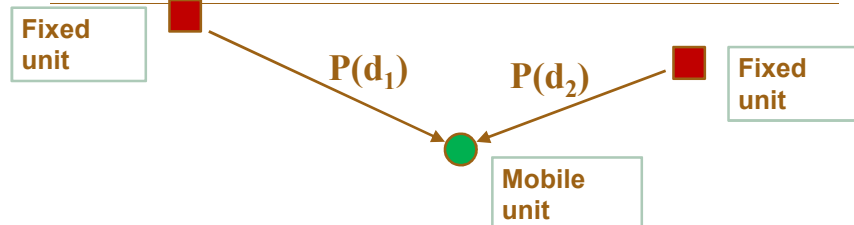
- Based on **bearing estimation** followed by intersection of different direction pointers
- Requires **antenna arrays** or **directive antennas** at measuring side: requires complex hardware
- Accuracy limited by size of antenna array or directivity
- No requirements on synchronization

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Received signal strength (RSS) based positioning



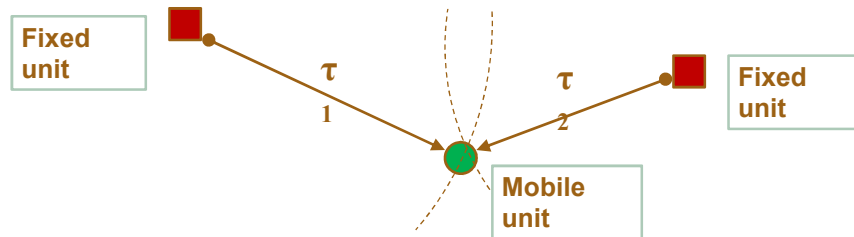
- Based on **propagation-loss equations**
- Propagation-loss is often more complex than free-space ($1/d^2$) loss, e.g., indoors
 - Advanced models required
 - Fingerprinting (learn actual field strength from measurements)
- Feasible implementation: Most radio modules already provide an RSS indicator

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Time-based positioning: Time-of-arrival (TOA)



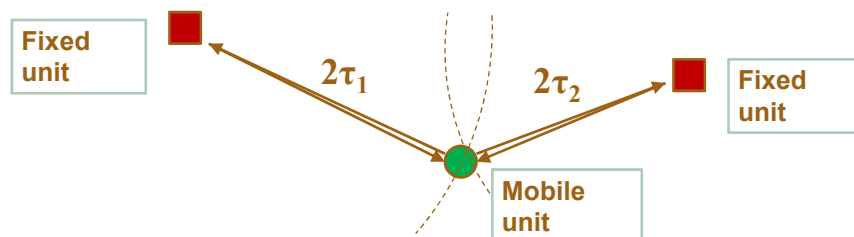
- Based on **one-way propagation time**
- Requires precise **synchronization** of all involved units (time synchronization directly affects accuracy)
 - Ex. A 1 ns clock drift implies a distance error of 0.3 m
- **Bandwidth** dependent (accuracy inversely proportional to bandwidth)
- Can provide higher accuracy than AOA and RSS methods

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Time-based positioning: Roundtrip-time-of-flight (RTOF)



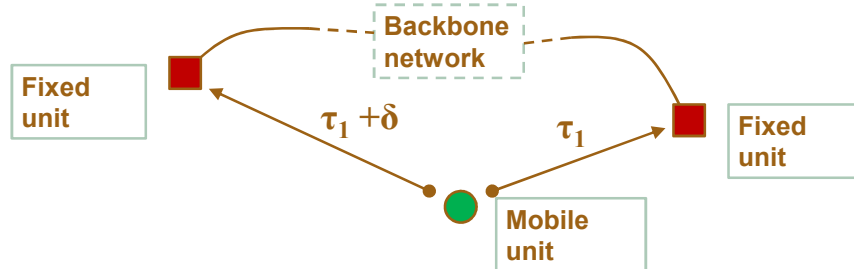
- Based on **roundtrip time (RTT)**
- Lower requirements on synchronization than TOA, but depends on **delay/processing time of responder**
 - Ex. Processing time of 1 ms can lead to an error of several meters
- **Bandwidth** dependent

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Time-based positioning: Time-difference-of-arrival (TDOA)



- Based on the **difference** in time-of-arrival measured in several pairs of measuring units
- Only receive units needs to be synchronized
 - Handled by backbone network for remote-positioning
- **Bandwidth** dependent

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GPS



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GPS

- Global Positioning System
- Started in 1978
- Operational in 1993



- Each satellite continually transmits messages that include
 - the time the message was transmitted
 - precise orbital information
 - the general system health and rough orbits of all GPS satellites (the almanac).

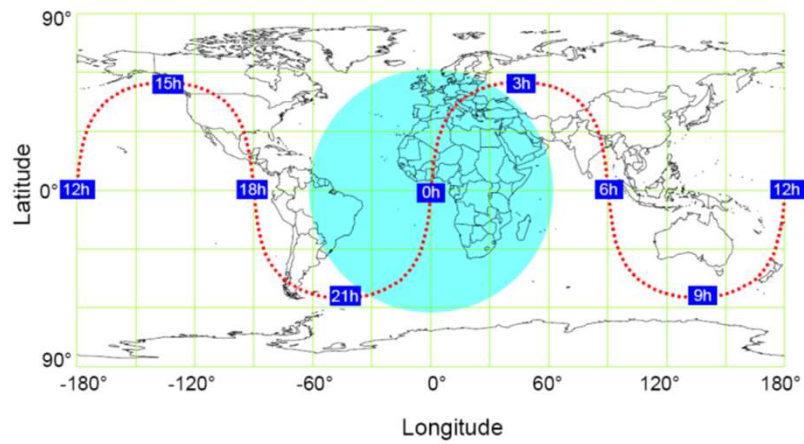
Satellites



24 satellites at 20 000 km above earth

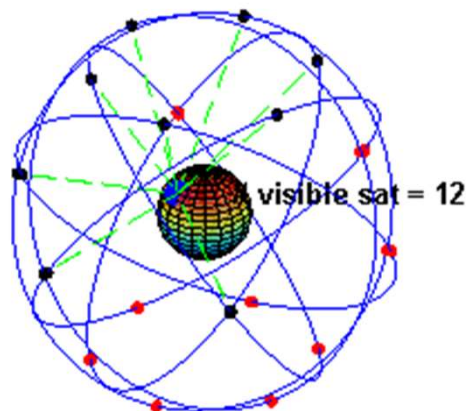
Orbits with a period of 11 hours 58 minutes, in order to always follow the same track on the earth surface.

Satellite track



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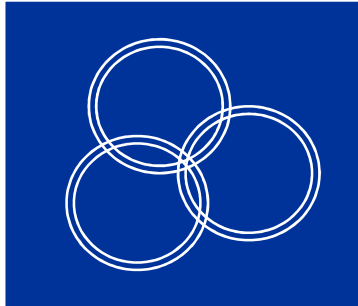
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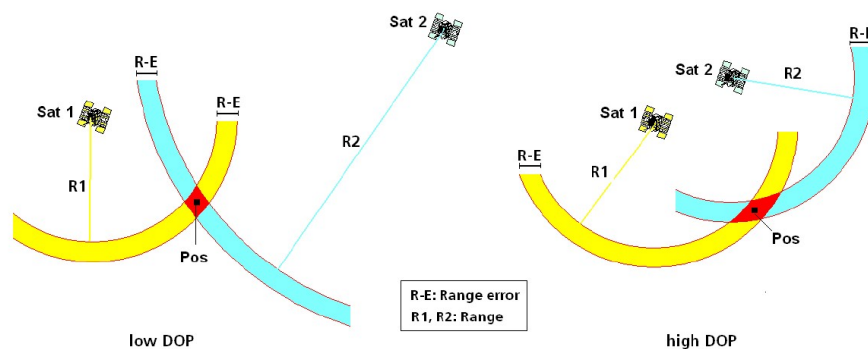
Solution:

- We need 4 satellites to get a position in three dimensions.
- Also, if we have access to more signals, we can correct for errors in the local clock.



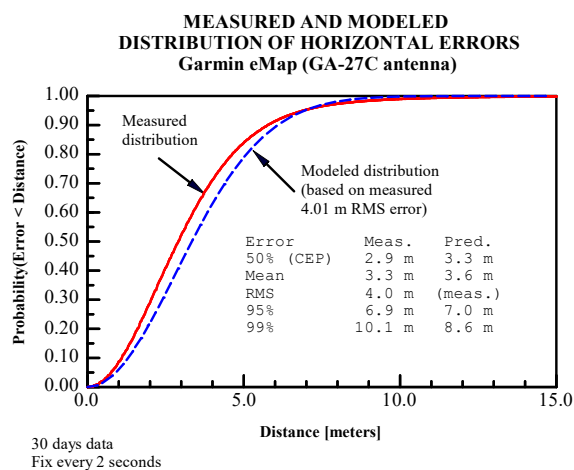
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Uncertainty in position: Dilution of precision (DOP)



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Error PDF (Probability Density function)



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Link Budget example

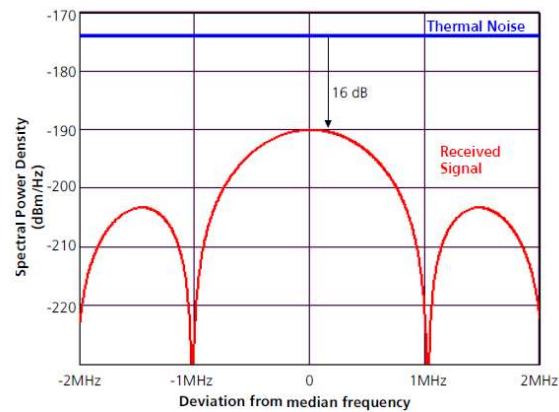
- Satellite TX: 14.3 dBW (27 W)
- Satellite antenna gain: +13.4 dB
- Polarization mismatch loss: 3.4 dB
- Path loss: 184.4 dB
- Atmospheric attenuation: 2.0 dB
- Receive antenna gain: 3.0 dB
- Power at receiver input: -160 dBW (10^{-16} W)

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Spectral power density of recieved signal

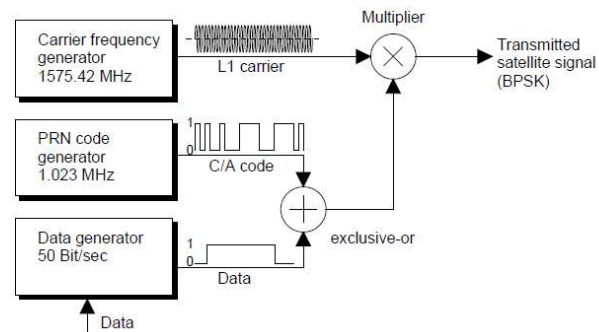


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Signal generation



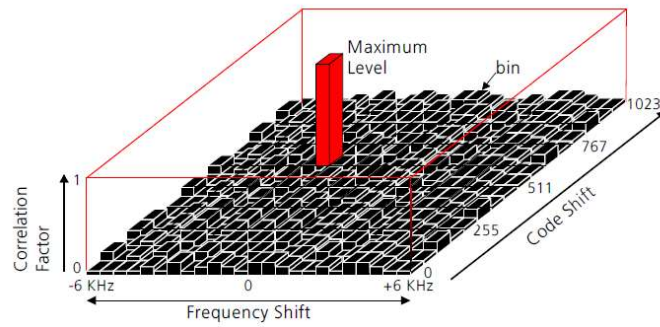
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Code acquisition

- Satellite speed: 7000 km/h
- Doppler shift: -6000 to +6000 Hz



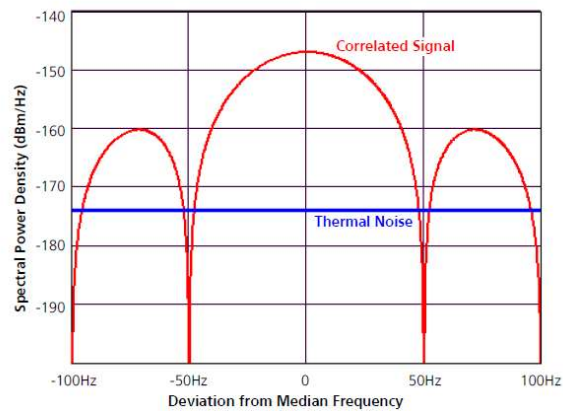
$$G_s = \frac{\text{Modulation rate of C/A - Code}}{\text{Data rate of information signal}} = \frac{1023\text{bps}}{50\text{bps}} = 20,500 = 43\text{dB}$$

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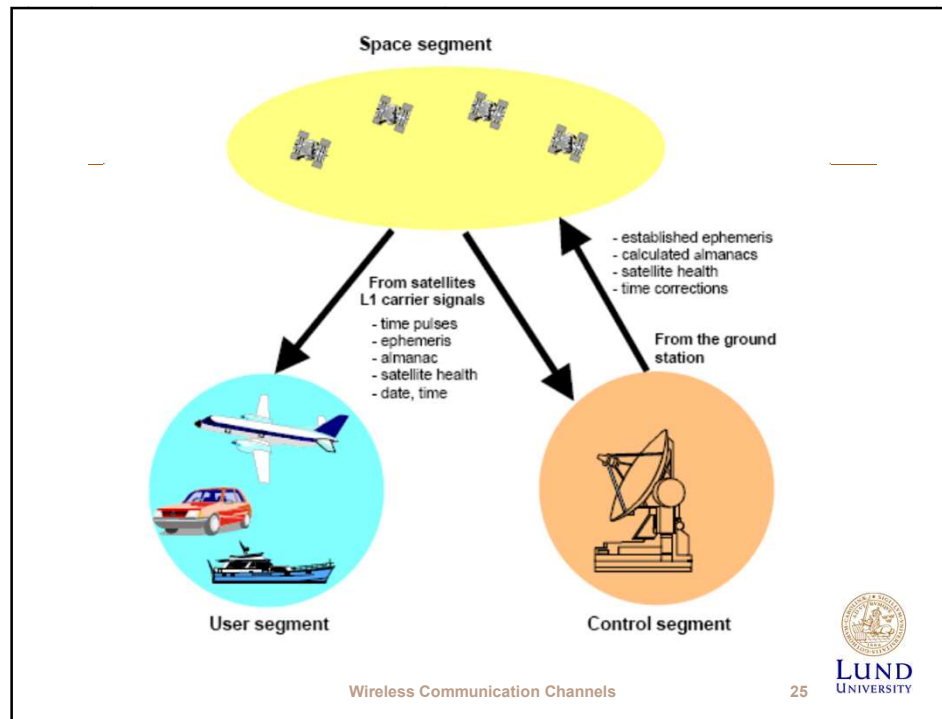
Spectral power density of corr. signal



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Base station positioning



GPS risks...



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Summary

- Wireless positioning techniques have numerous applications
- There are three fundamental principles for wireless positioning:
 - Angle-of-arrival (AOA) based methods
 - Received signal strength (RSS) methods
 - Time-based methods
- GPS, GPS, GPS, GPS...

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