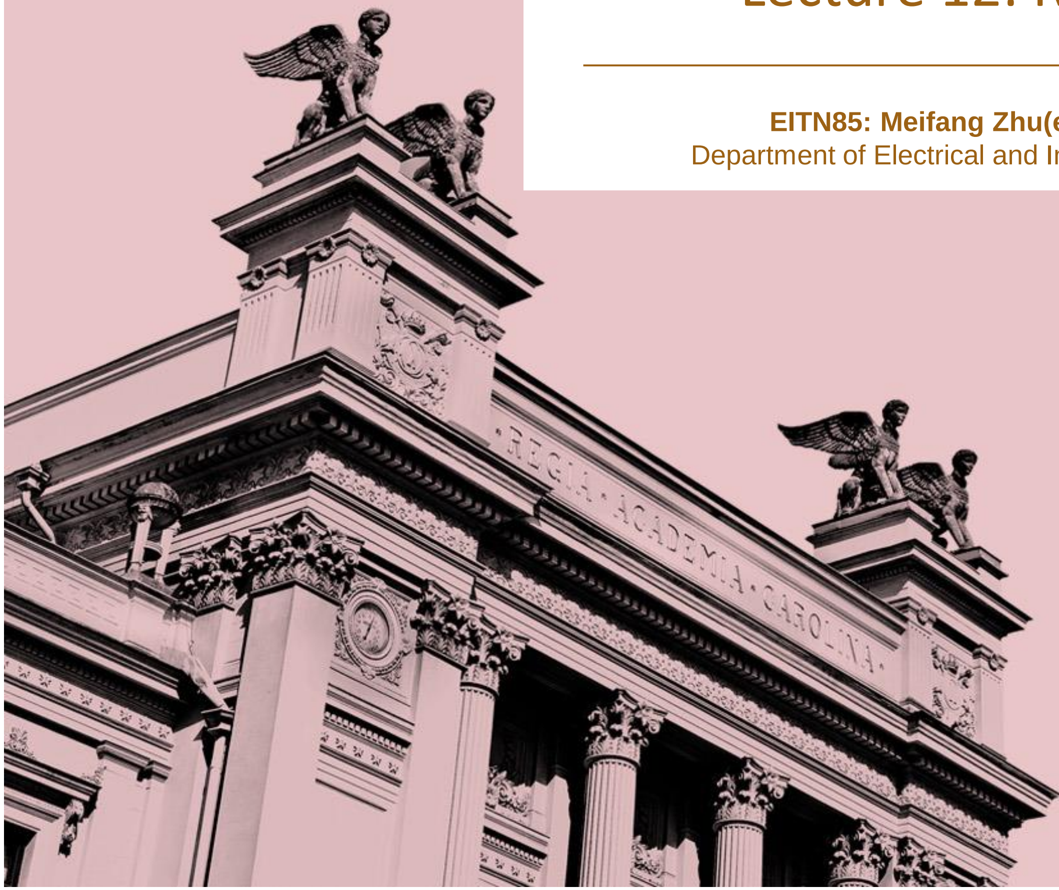
Wireless Communications Channels
Lecture 12: Radio-Based Positioning

EITN85: Meifang Zhu(e-mail: meifang.zhu@eit.lth.se)
Department of Electrical and Information Technology, Lund University



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…

Core principles for wireless positioning

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)

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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

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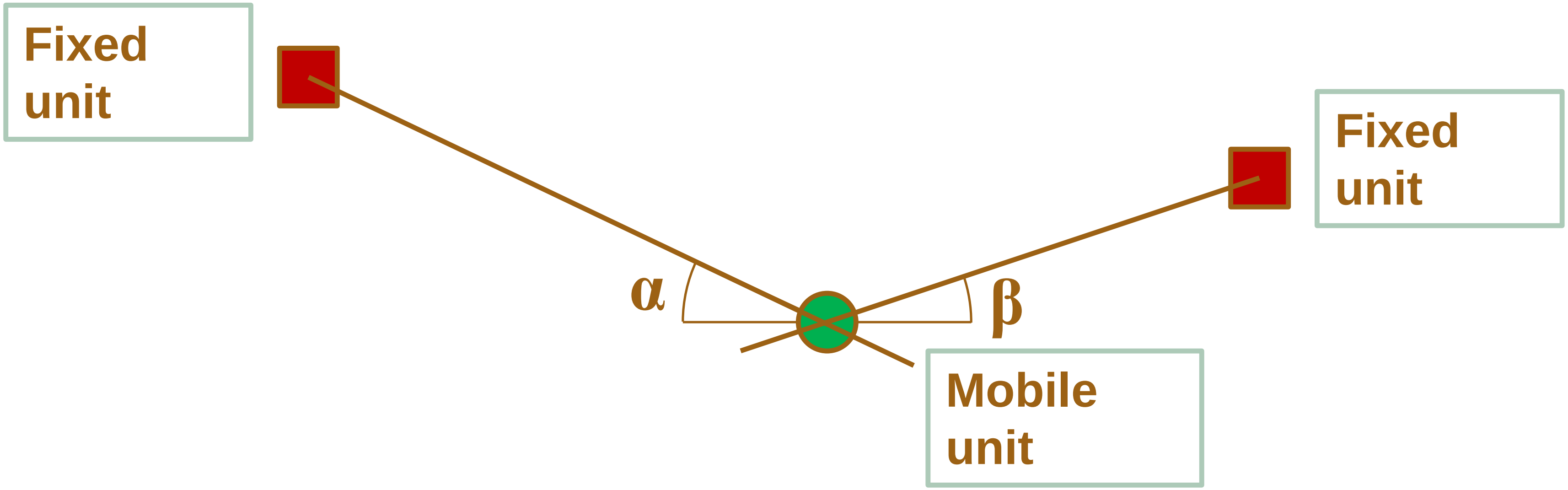
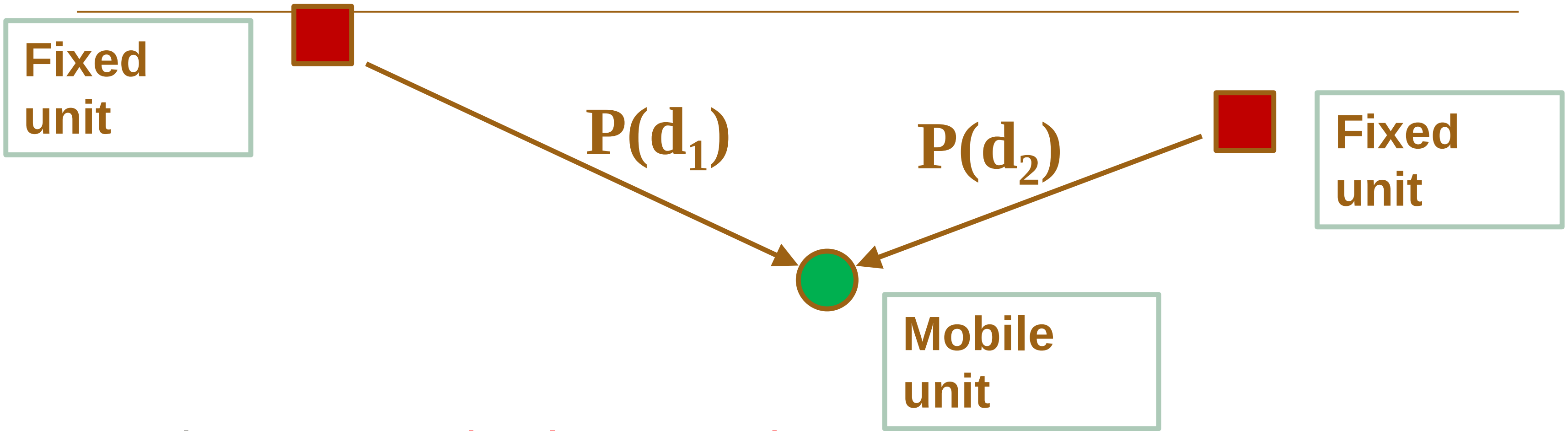
Angle-of-arrival (AOA)-based positioning



- 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

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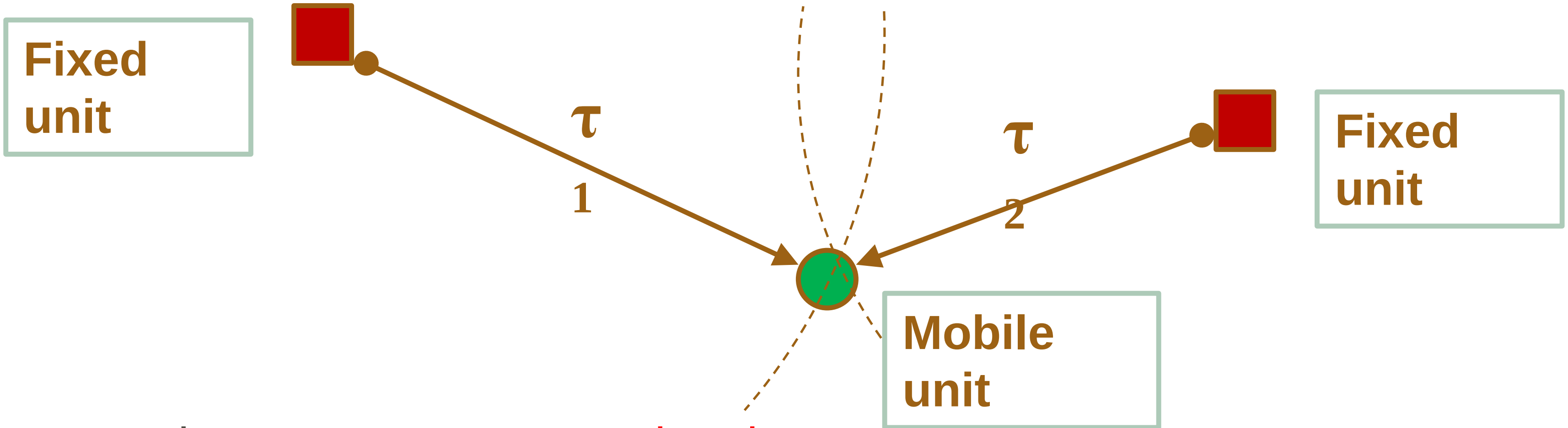
Time-based positioning: Time-of-arrival (TOA)



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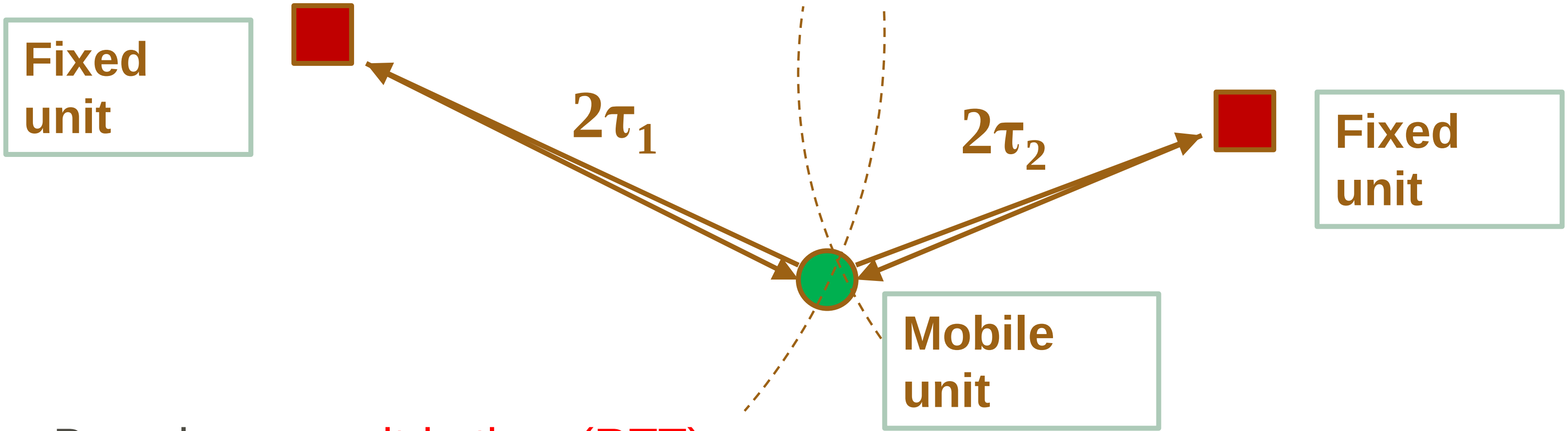
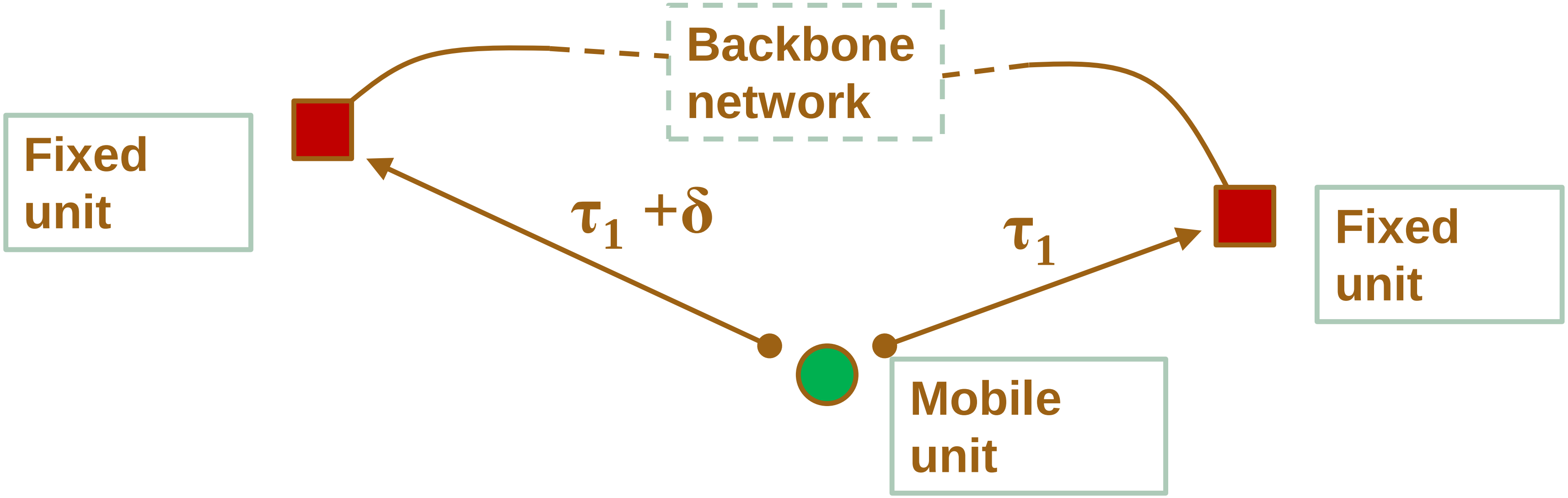
Time-based positioning: Roundtrip-time-of-flight (RTOF)



- 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

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

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).

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Satellites

24 sattelites 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.

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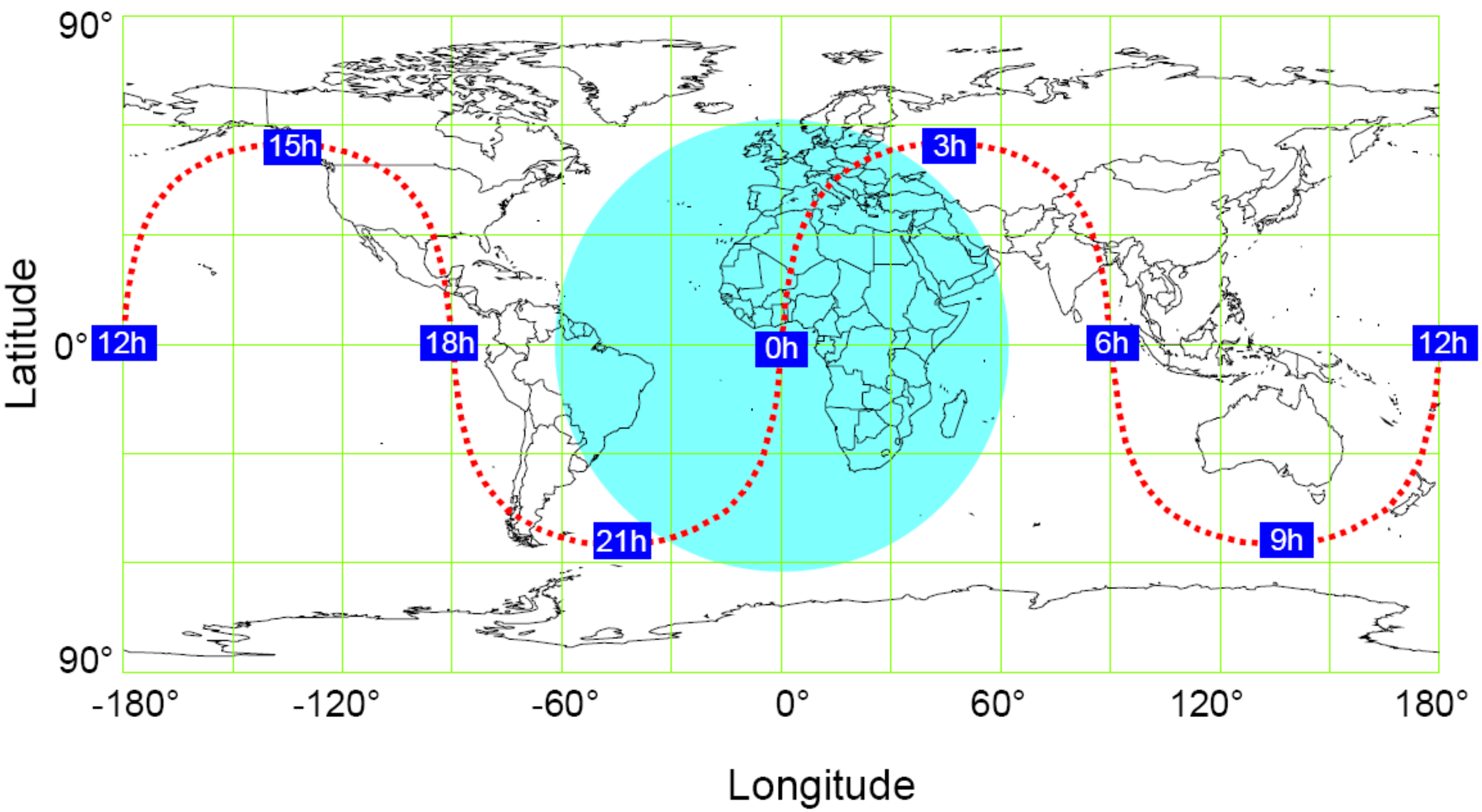
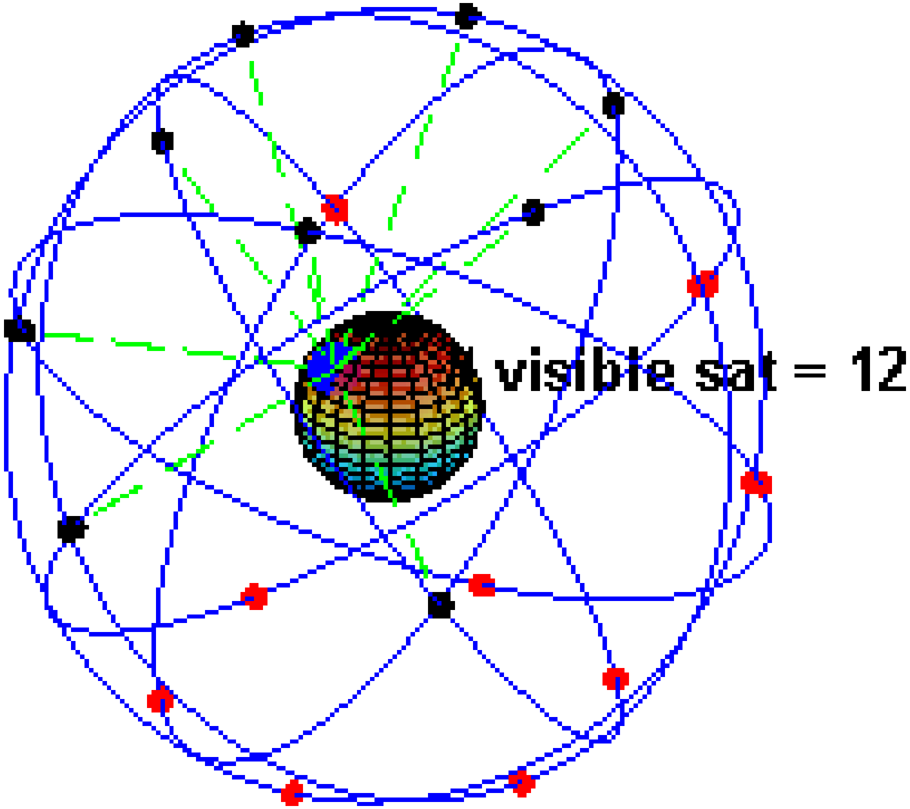
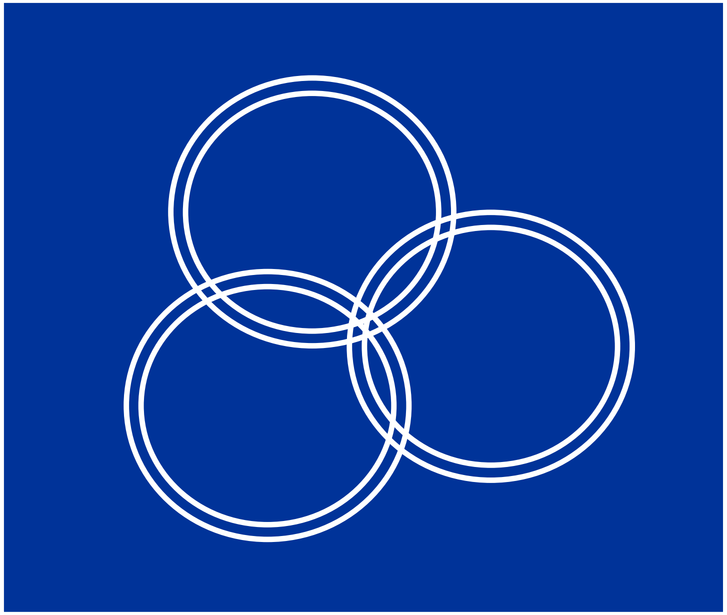
Satellite track




visible sat = 12

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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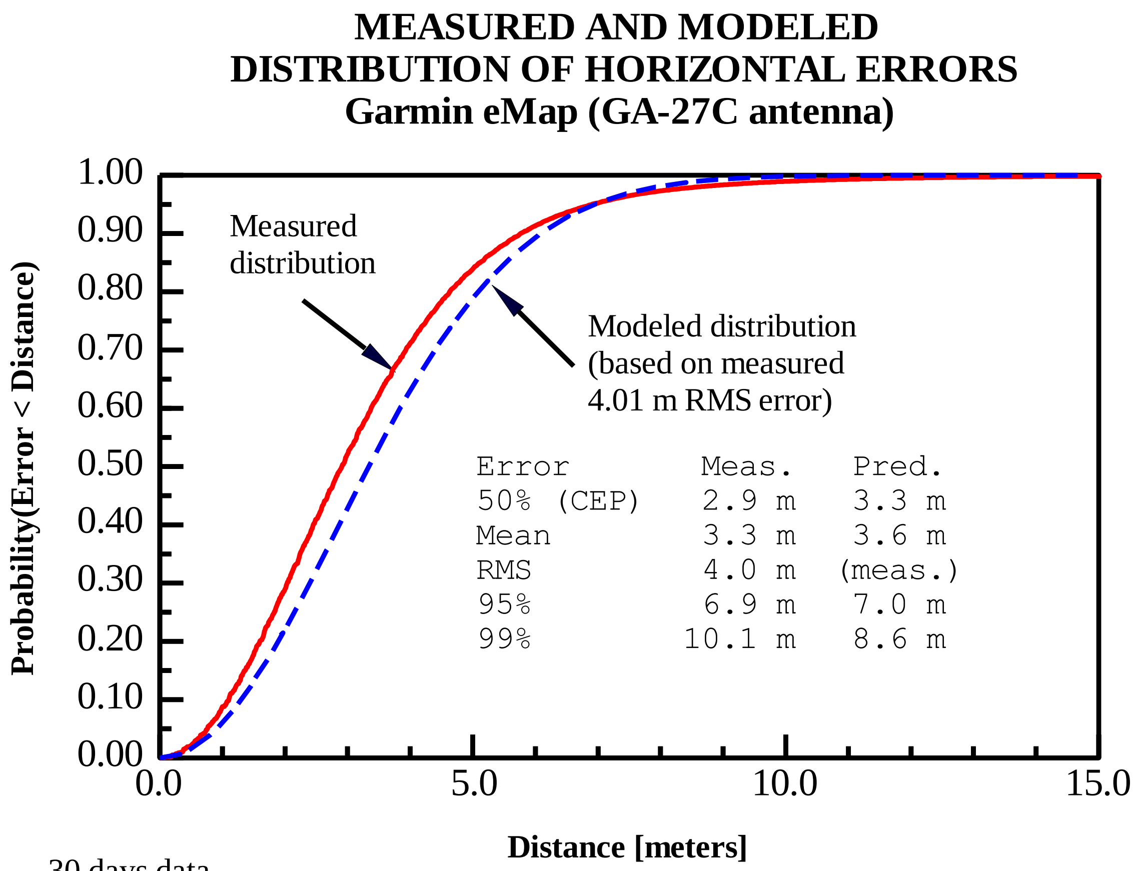
Error PDF (Probability Density function)

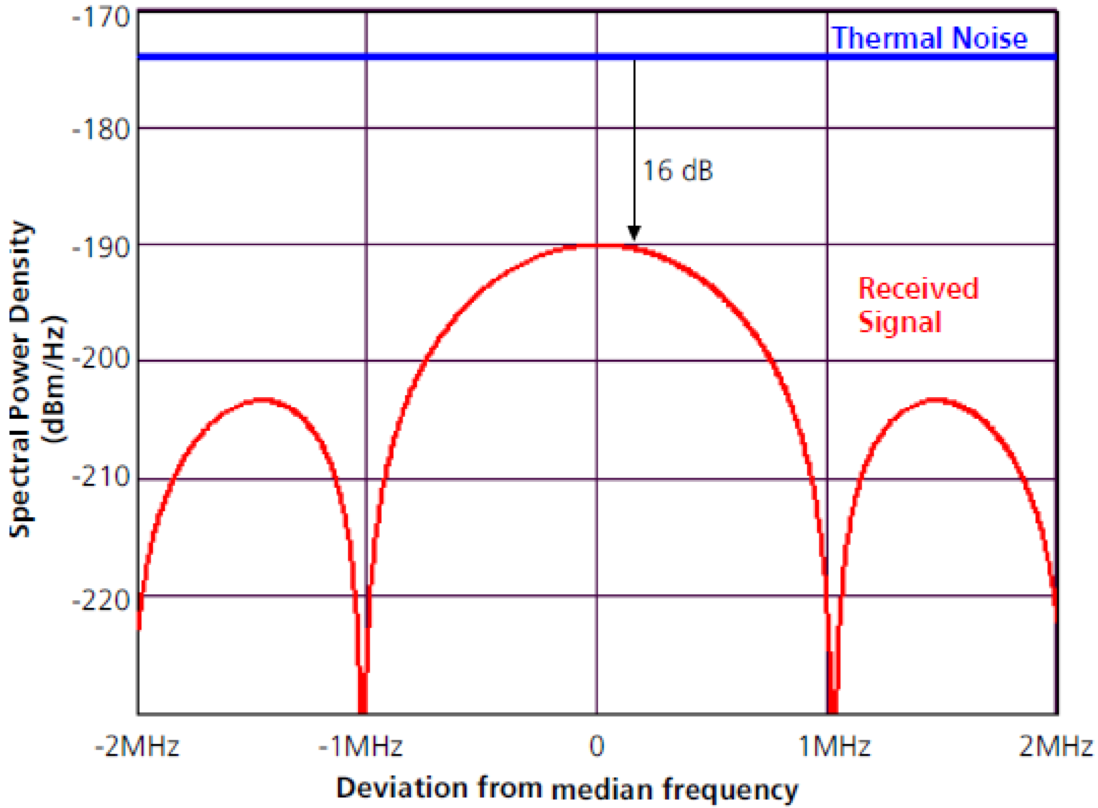


30 days data
Fix every 2 seconds

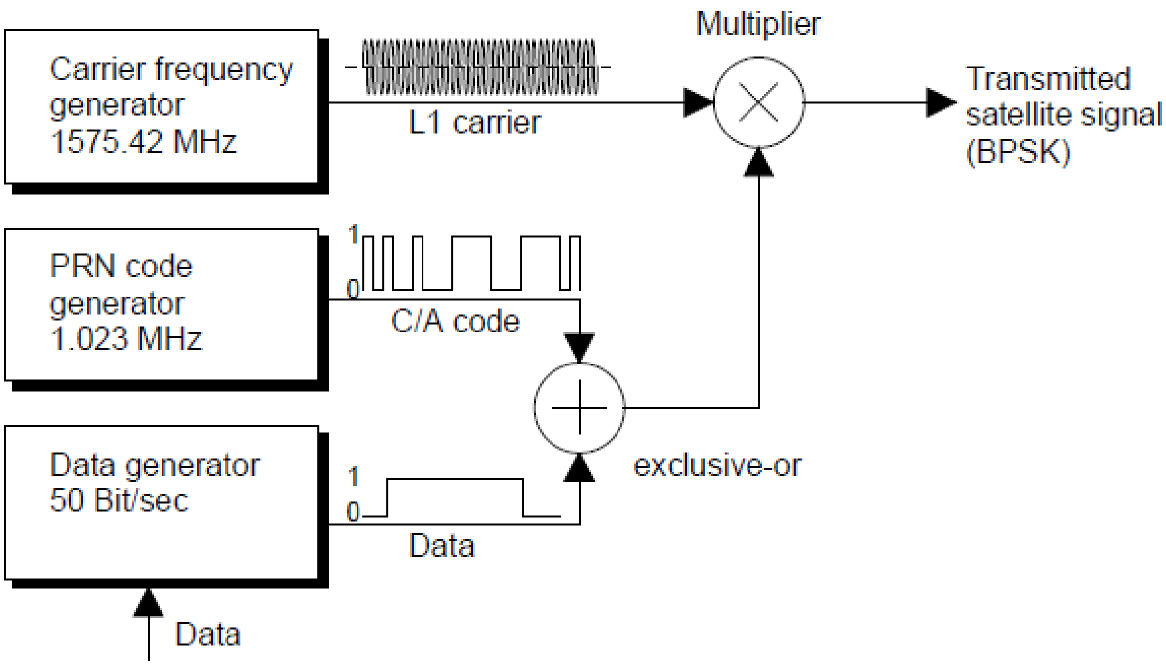
Link Budget example

- 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
- Recieve antenna gain: 3.0 dB
- Power at reciever input: -160 dBW (10^{-16} W)

Spectral power density of recieved signal



Signal generation



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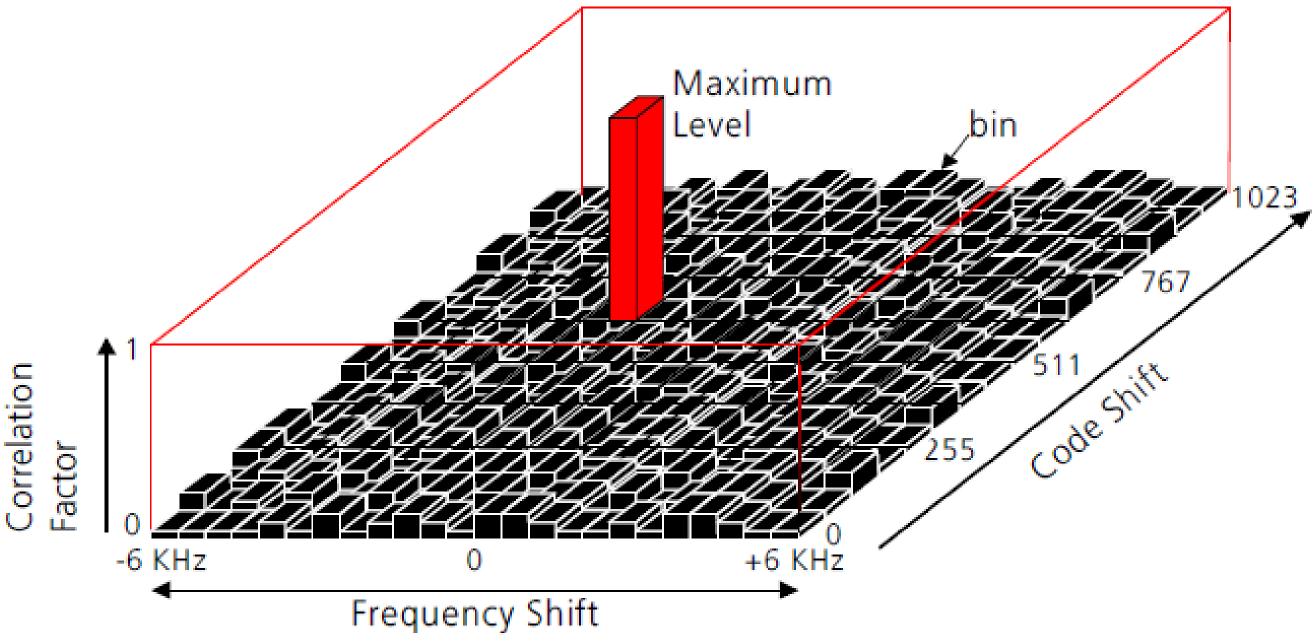
Code acquisition

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



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

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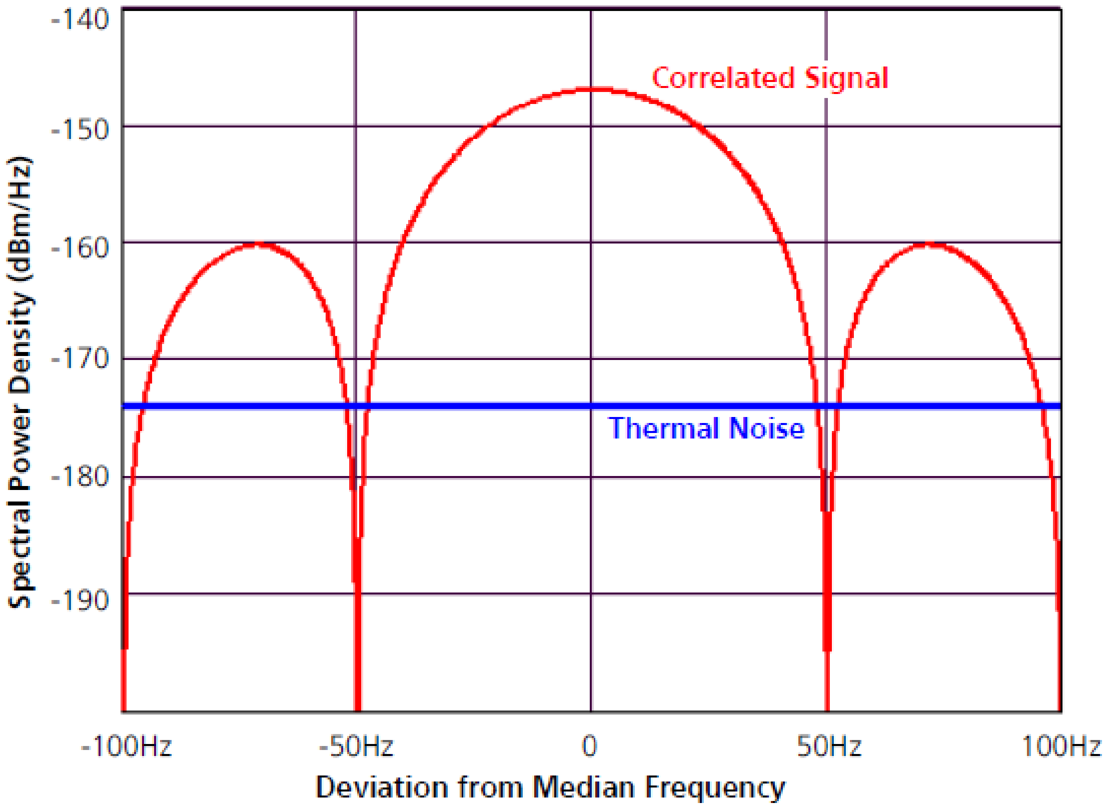
Spectral power density of corr. signal



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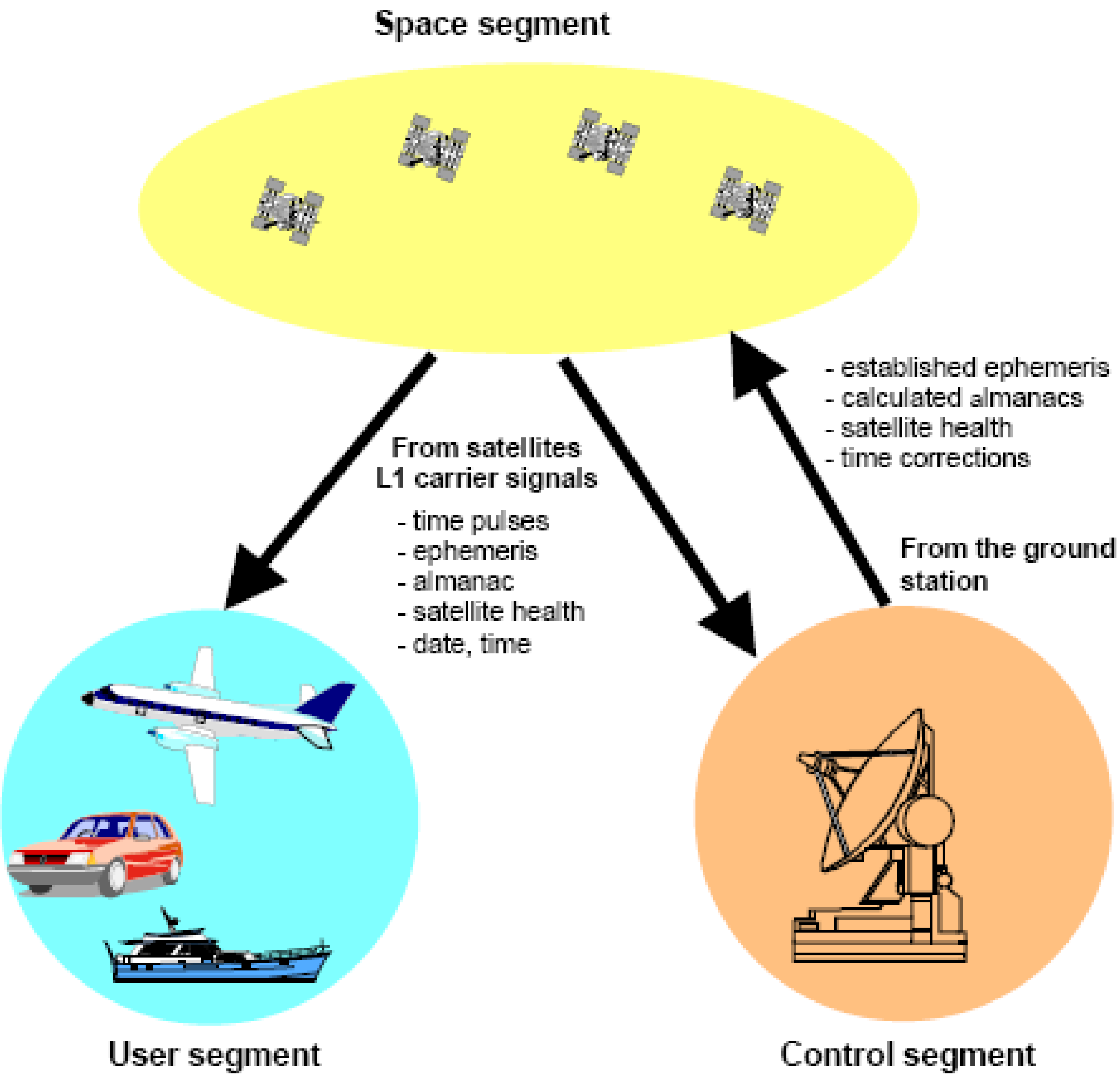
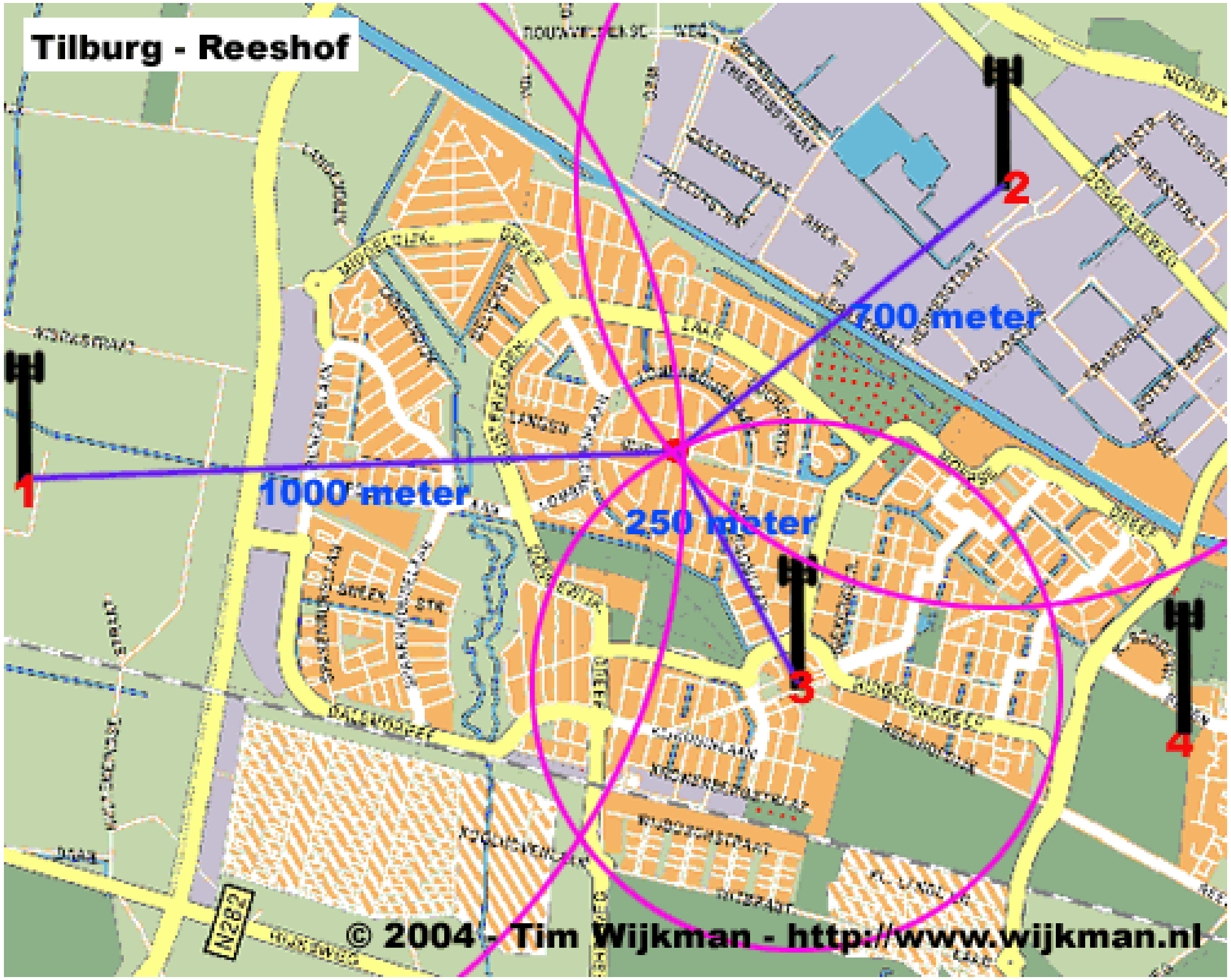

Space segment
From satellites
L1 carrier signals
- time pulses
- ephemeris
- almanac
- satellite health
- date, time
- established ephemeris
- calculated almanacs
- satellite health
- time corrections
From the ground
station
User segment
Control segment

Base station positioning



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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

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