

## Overview

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

## Why are we interested in wireless positioning?

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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

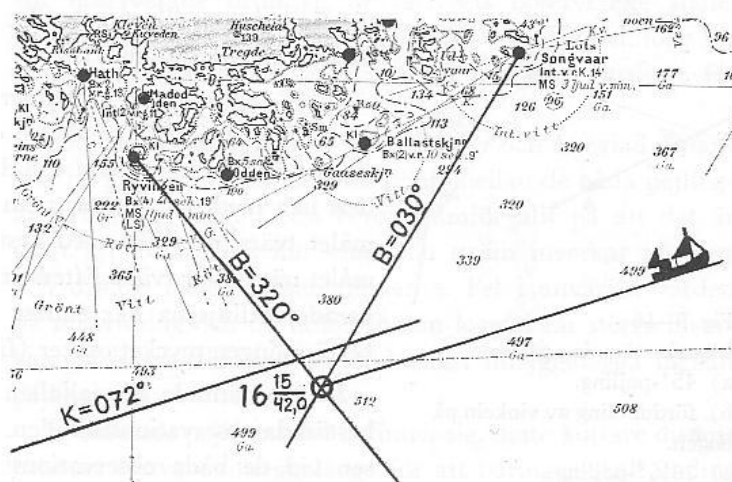
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## Classical navigation



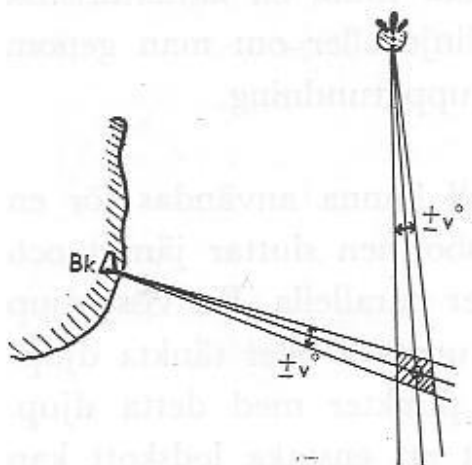
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## Errors in angle translate to position error



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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)

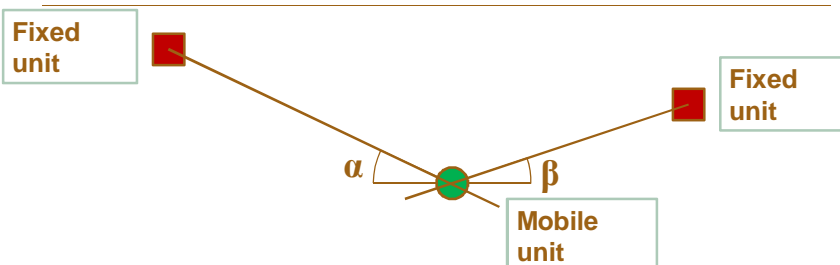
## Techniques for wireless positioning

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

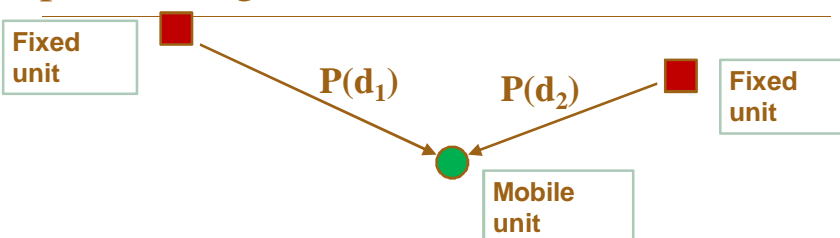
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## Received signal strength (RSS) based positioning



- 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

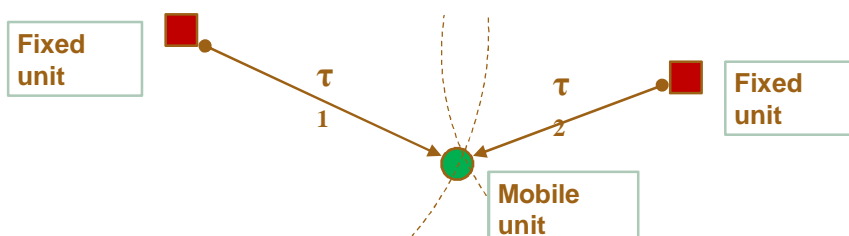
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## Time-based positioning: Time-of-arrival (TOA)



- 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

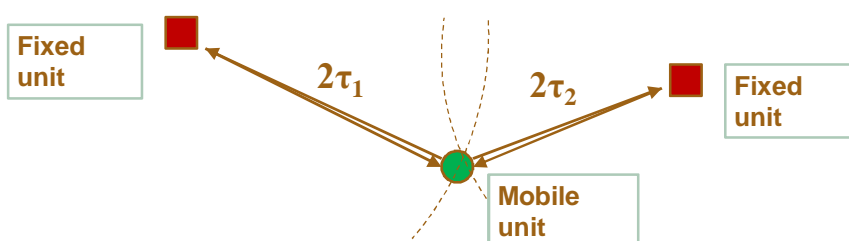
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## Time-based positioning: Roundtrip-time-of-flight (RTOF)



- 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

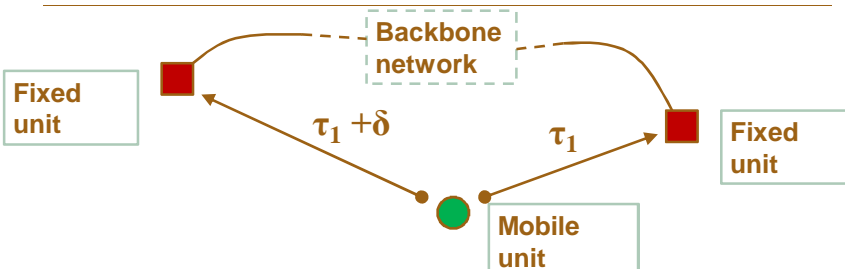
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## Time-based positioning: Time-difference-of-arrival (TDOA)



- 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).

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## 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.

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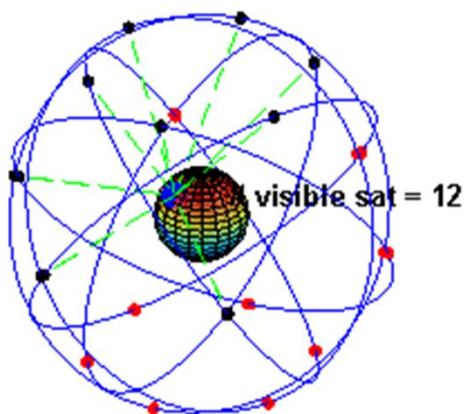
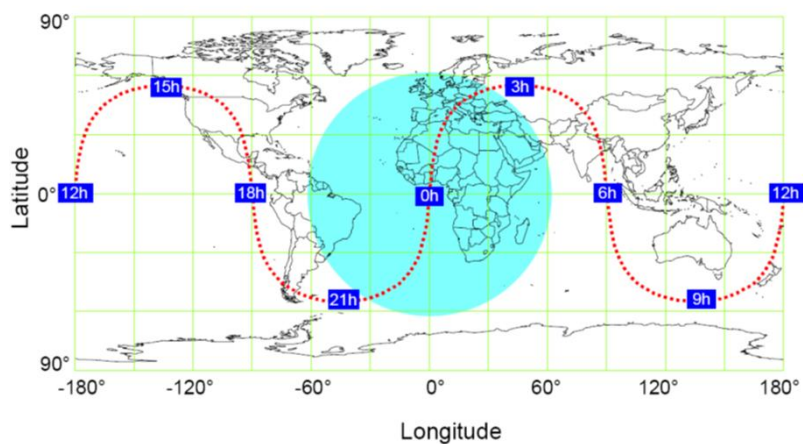
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16



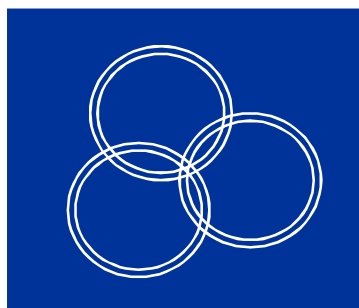


### Satellite track



## Solution:

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



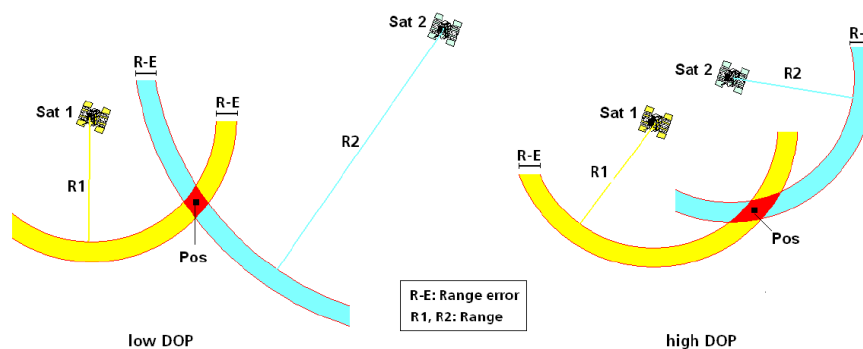
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## Uncertainty in position: Dilution of precision (DOP)



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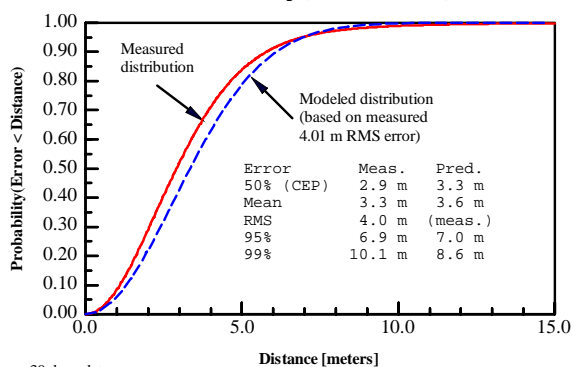
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## Error PDF (Probability Density function)

**MEASURED AND MODELED DISTRIBUTION OF HORIZONTAL ERRORS**  
Garmin eMap (GA-27C antenna)

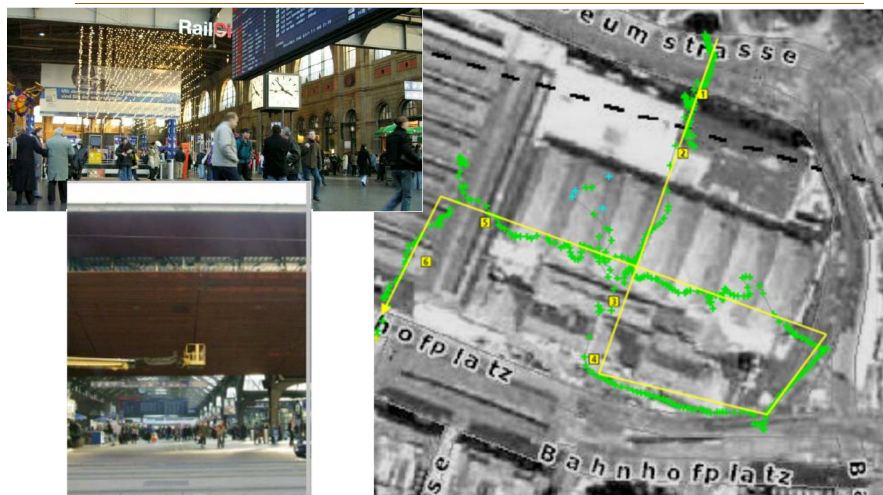


30 days data  
Fix every 2 seconds

## Indoor GPS



## Train station



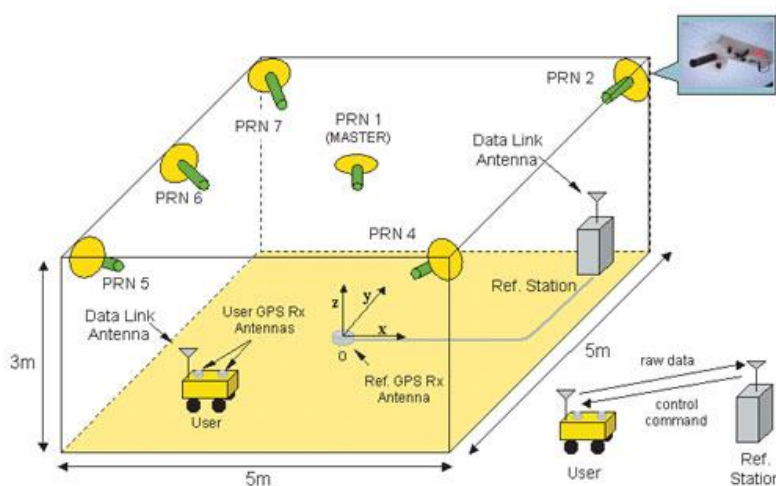
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## Local transmitters:

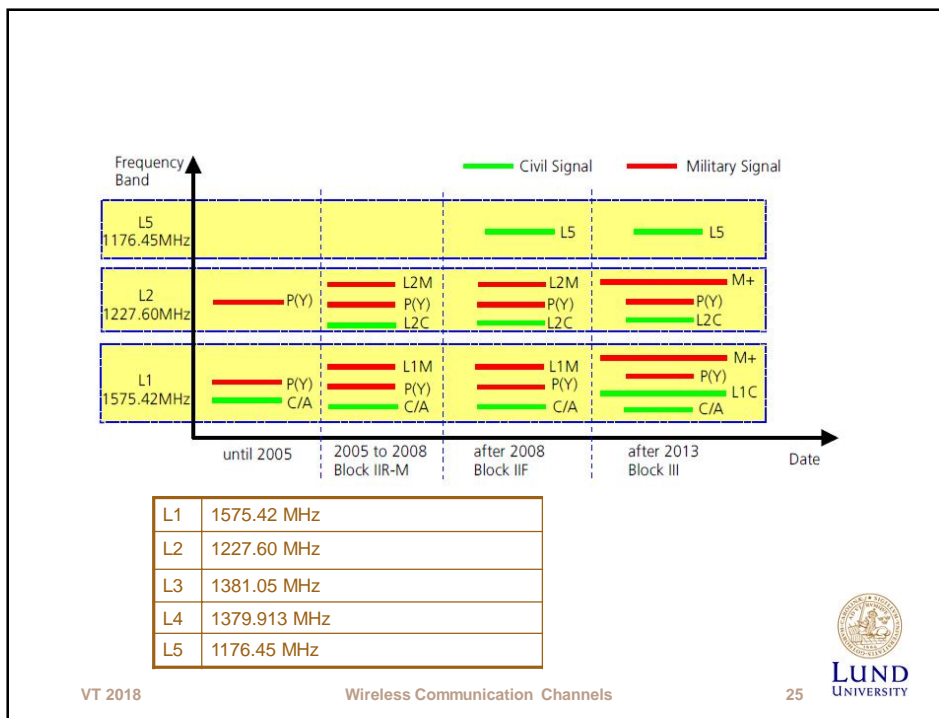


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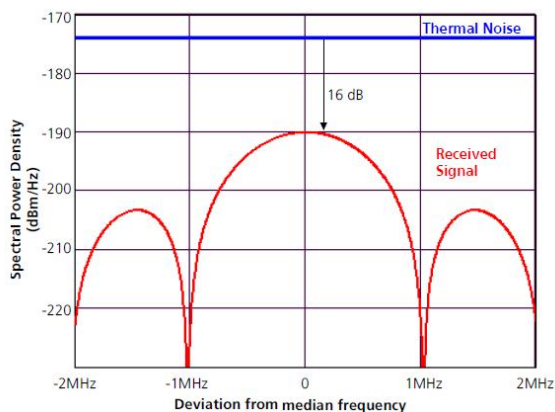




## Link Budget example

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

## Spectral power density of recieved signal



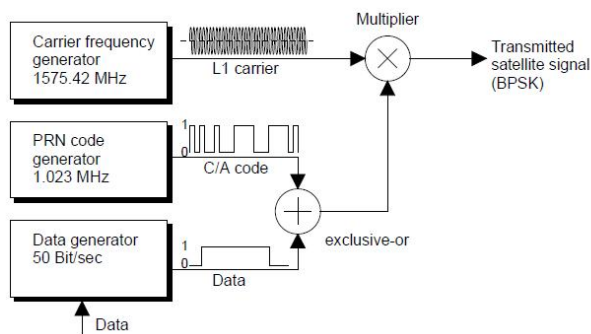
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## Signal generationi



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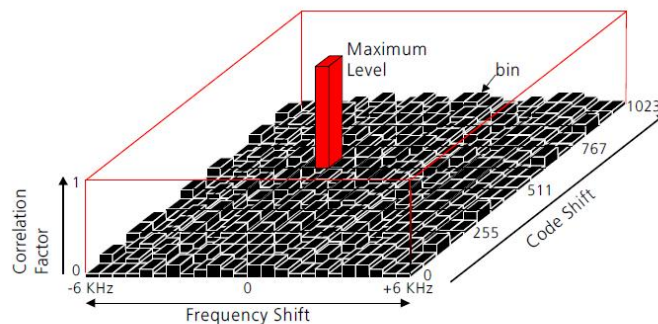
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## Code acquisition

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



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

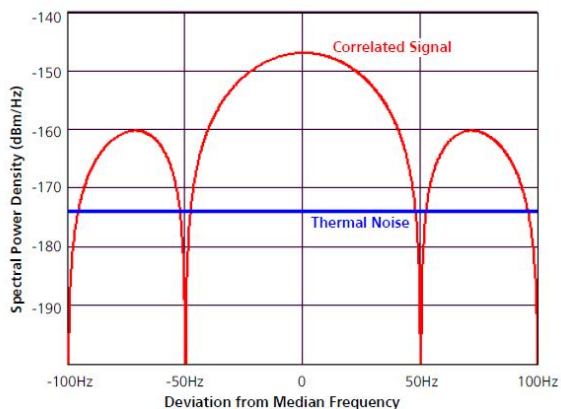
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## Spectral power density of corr. signal



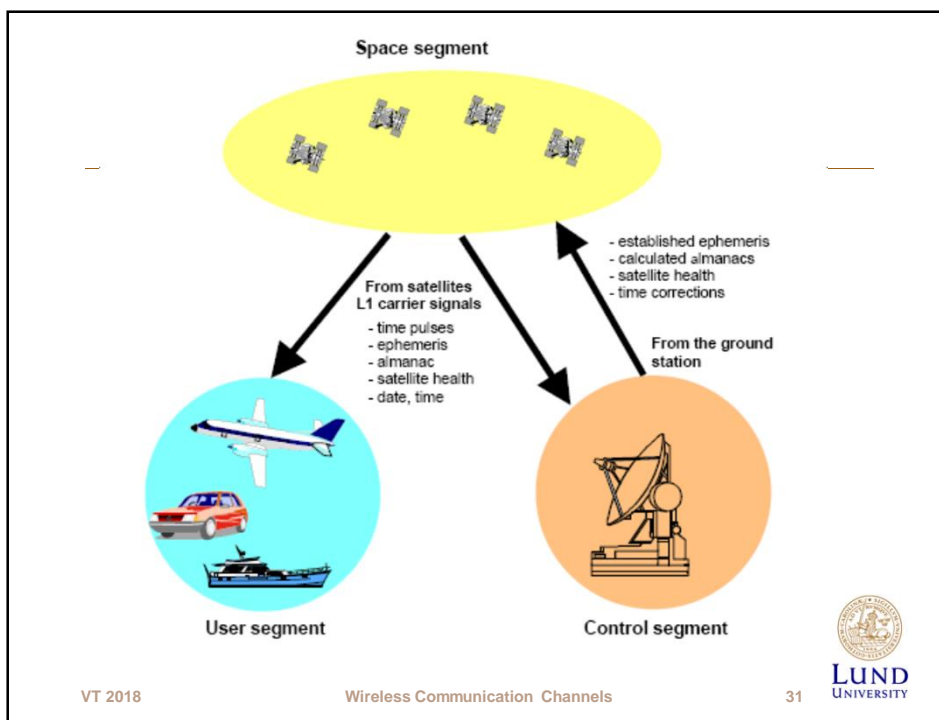
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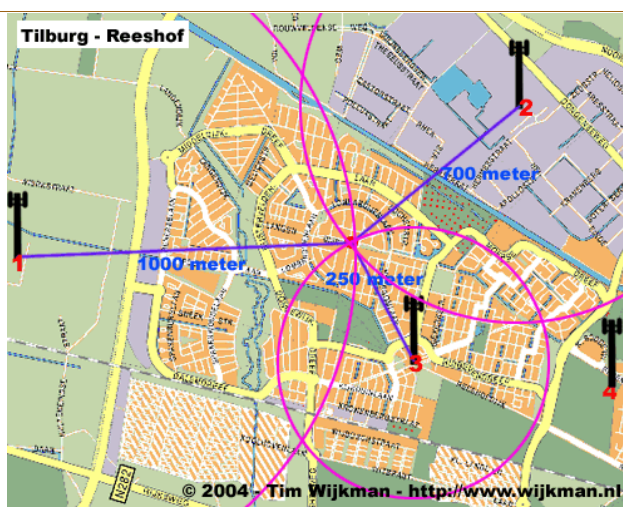
30







## 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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