LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Praktikum Mobile und Verteilte Systeme

Outdoor Positioning Systems

André Ebert, Sebastian Feld
http://www.mobile.ifi.lmu.de

Wintersemester 2017/18

Outdoor Positioning Systems - Introduction

Today:

- History of Positioning
- Positioning Fundamentals
- GPS – Global Positioning System
  - System architecture
  - Position calculation
- Galileo
  - Enhancements

1. History of Positioning I

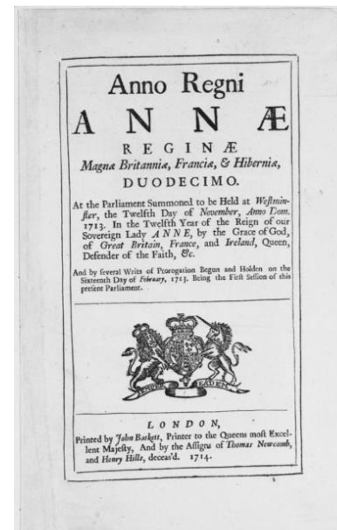
- **Magnetic Compass** (<5th Century in China, then 13th Century in Europe)
- **Octant**, then **Sextant** (18th Century): measurement of height of objects (sun, stars) above horizon, maximum height gives latitude
- **Chronometer** (maritime clock) with +/- 1s stability per day (Harrison, 1761)
  – 1 second error means a 450 m longitude error at the equator (caused by the rotation of the earth)
- With **Sextant/Octant** best position accuracy is **1 NM**

www.landandsealocation.com

1. History of Positioning II

- In 1714, following many maritime accidents (including more than 1500 vanished with the loss of the fleet of admiral Clowdisley Shovell in 1707), the British government settled the **“longitude act”** to offer a 20.000 pounds reward (more than today´s 10 millions €) for a method to determine the longitude

- Expected accuracy (drift):
  – Maximum error: **0,5 degrees**
  – 0,5 degrees = **30 nautical miles** at the equator
    = motion during 2 minutes of earth rotation
    = 3 seconds per day during 40 days
    (40 days = a 6 week journey from England to the West Indies)


Anno Regni
ANNÆ
REGINÆ
Magnæ Britanniæ, Franciæ, & Hiberniæ,
DUODECIMO.

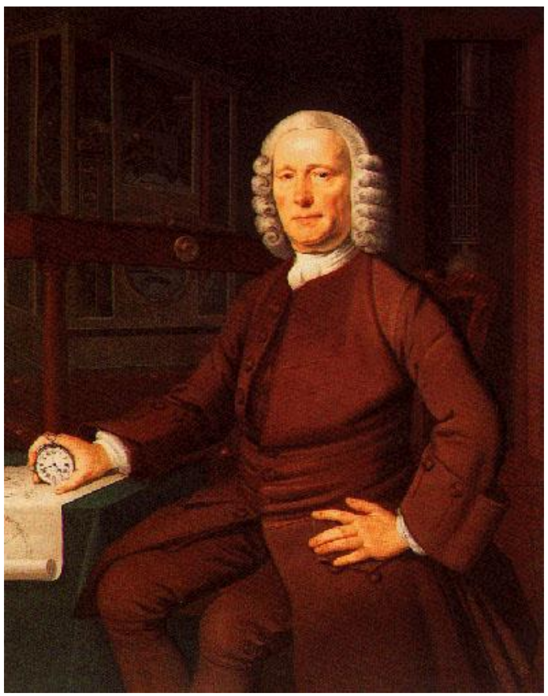
At the Parliament Summoned to be Held at *Westminster*, the Twelfth Day of *November*, *Anno Dom.* 1713. In the Twelfth Year of the Reign of our Sovereign Lady *ANNE*, by the Grace of God, of *Great Britain*, *France*, and *Ireland*, Queen, Defender of the Faith, &c.

And by several Writs of Prorogation Begun and Holden on the Sixteenth Day of *February*, 1713. Being the First Session of this present Parliament.

LONDON,
Printed by *John Baskett*, Printer to the Queens most Excellent Majesty, And by the Assigns of *Thomas Newcomb*, and *Henry Hills*, deceas'd. 1714.

1. History of Positioning III

- John Harrison (1693 – 1776)
- Drift on H4 clock: 39.2 seconds after 47 days (4 times better than what was requested)



H1

H2

H3

H4
13cm
1.45 kg

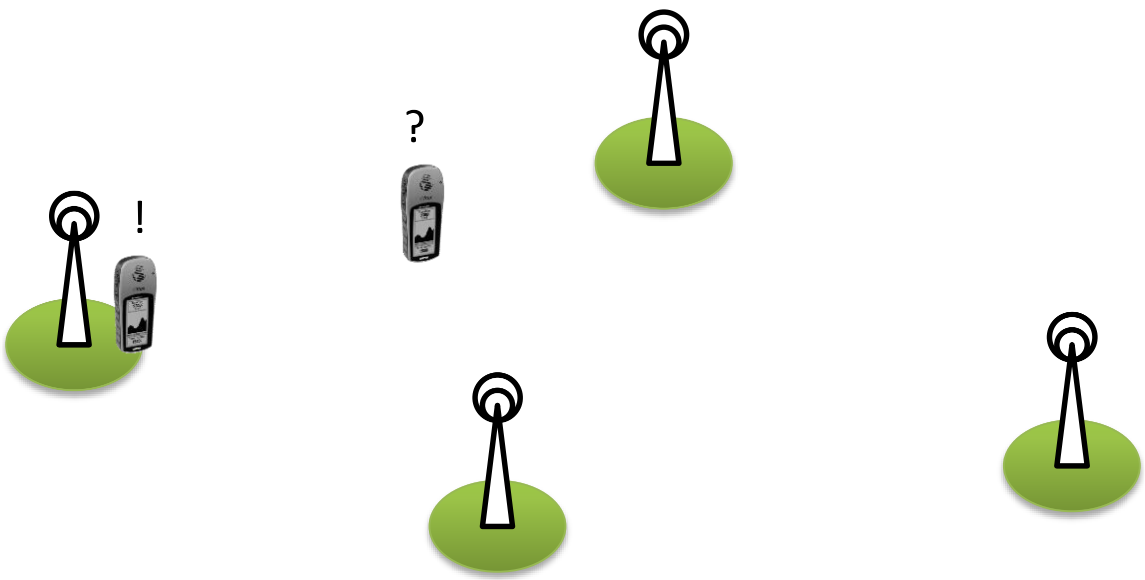
2. Positioning Fundamentals – Components

- Positioning is determined by
  - one or several **parameters observed by measurement methods**
  - a positioning method for position calculation
  - a descriptive or spatial reference system
  - an infrastructure
  - protocols and messages for coordinating positioning

Positioning method	Observable	Measured by
Proximity sensing	Cell-ID, Coordinates, RSS	Sensing for pilot signals
Lateration	Range or Range difference	Traveling time of pilot signals Path loss of pilot signals Traveling time difference of pilot signals Path loss difference of pilot signals
Angulation	Angle	Antenna arrays
Dead reckoning	**Position** and **Direction** of motion and **Velocity** and **Distance**	Any other positioning method Gyroscope Accelerometer Odometer
Pattern matching	Visual images or Fingerprint	Camera Received signal strength

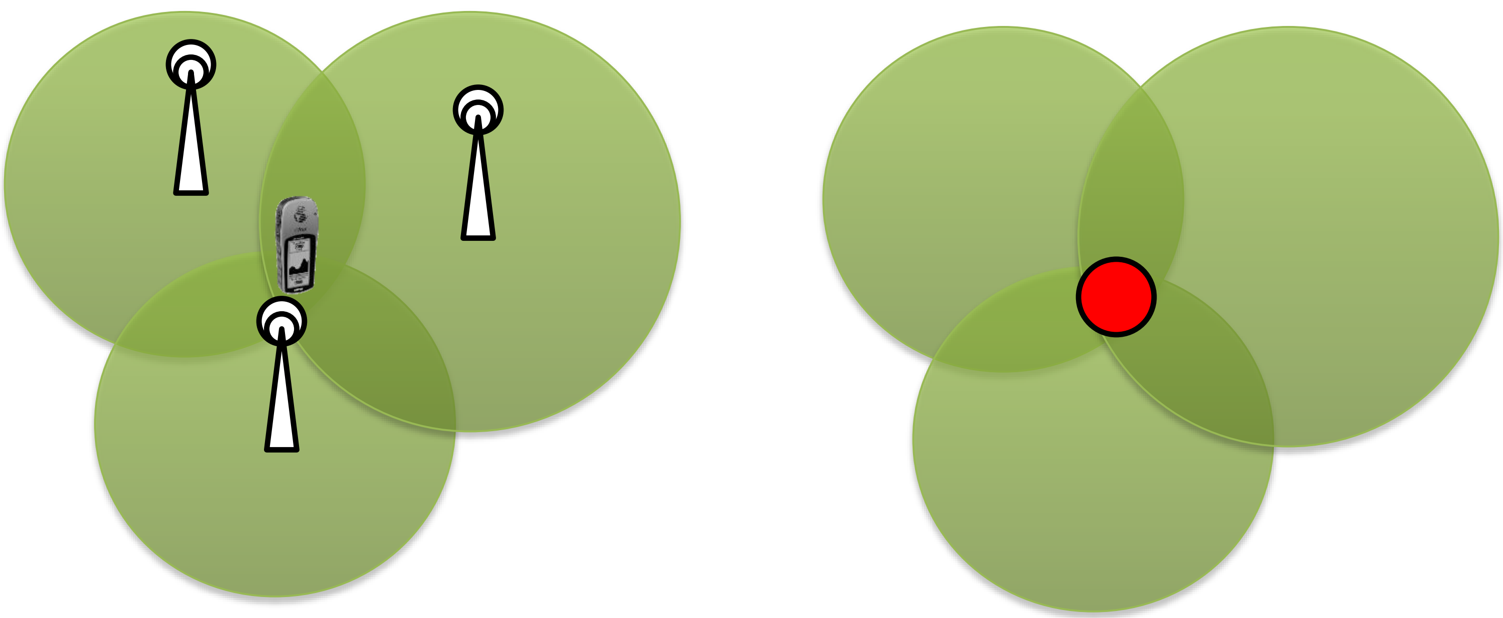
Proximity Sensing

- Proximity is sensed by a station using (short) range pilot signals:



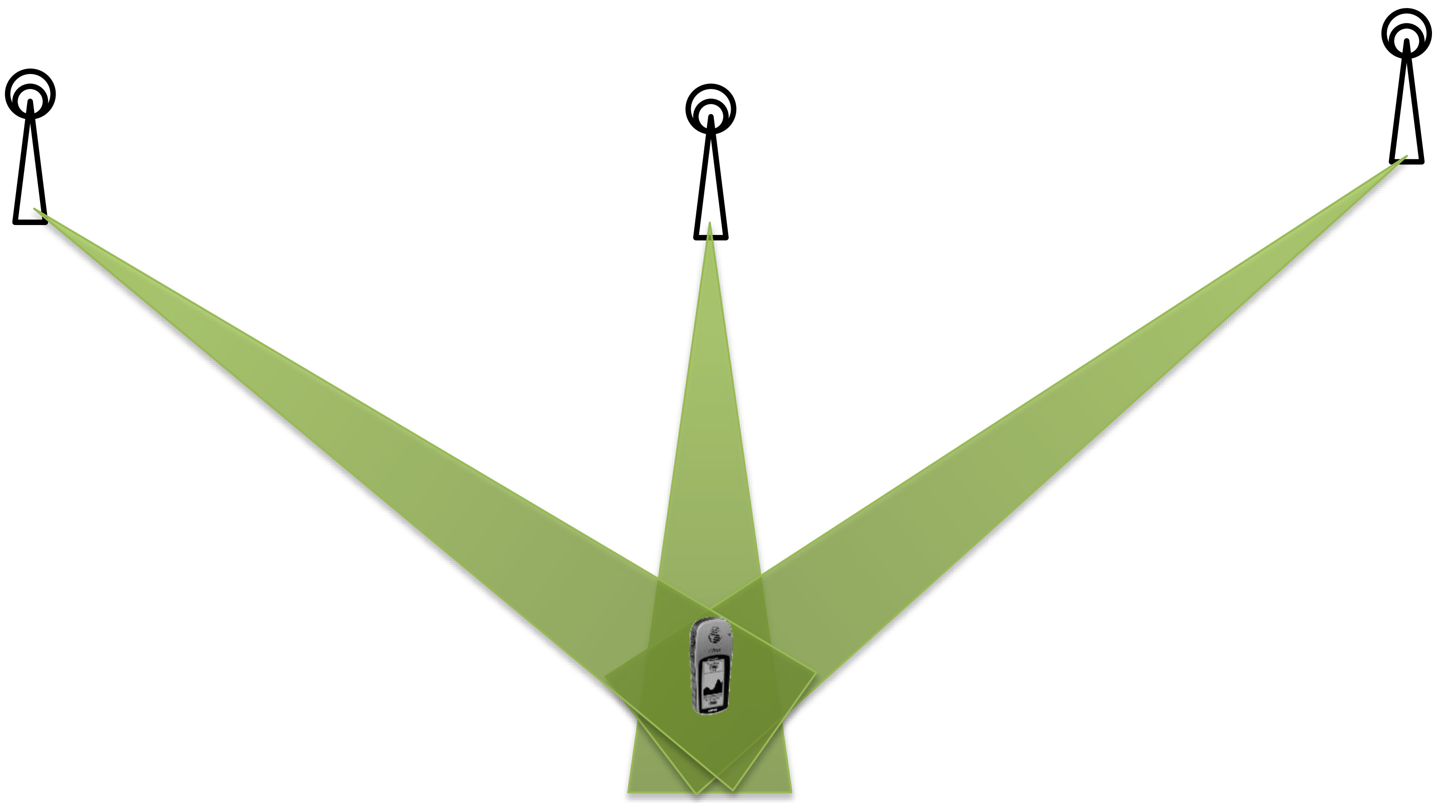
Lateration

- Position is computed by a number of **range measurements** to **known fix-points**:



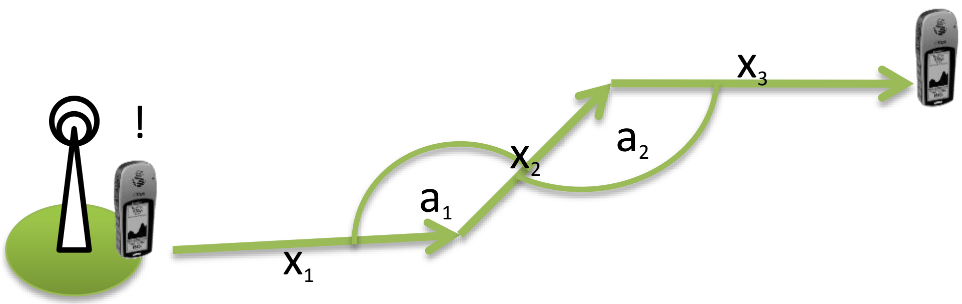
Angulation

- Position is derived by the measured of the **angle of an arriving signal** by multiple stations **at known fix-points**:



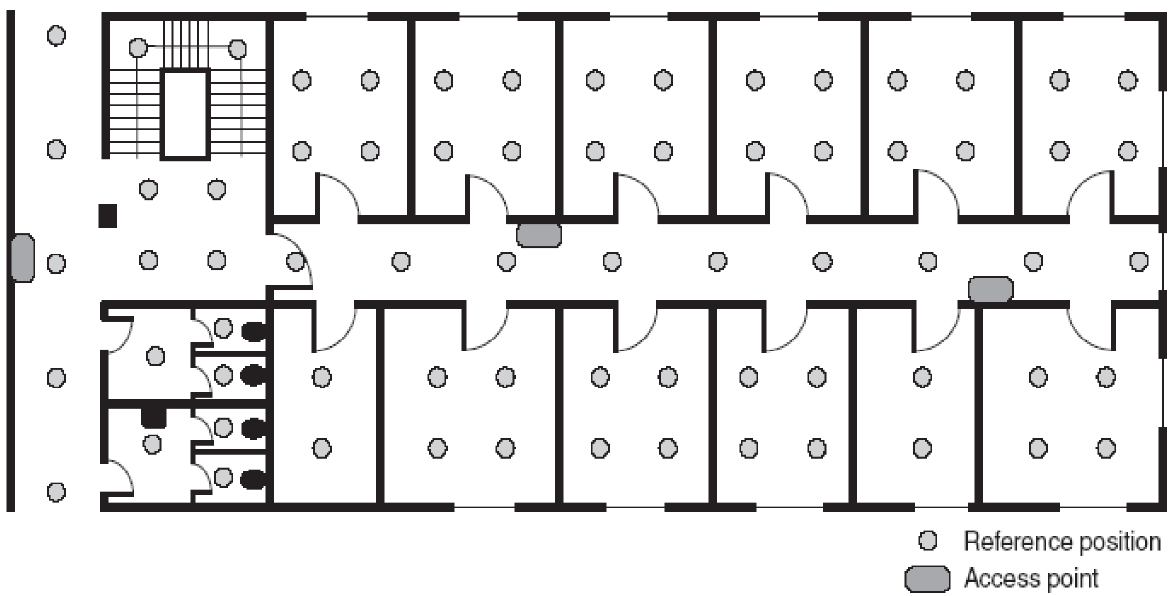
Dead Reckoning

- From a **known starting position**, the movement of the mobile device is estimated (e.g., using velocity and direction of movement):
- Position becomes more inaccurate with each estimation
- Recalibration necessary!



Fingerprinting

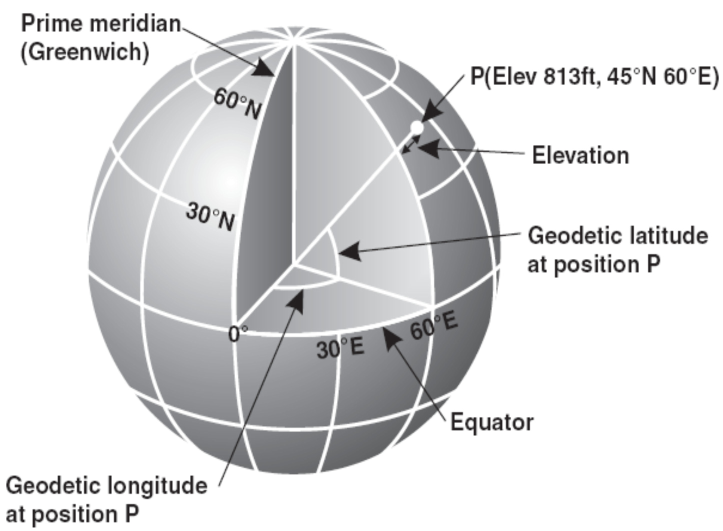
- Position is derived by the comparison of location dependent online measurements with previously recorded data:

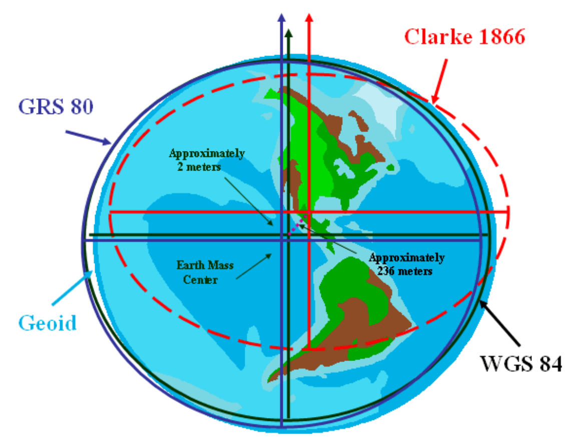


- See Mobile Sensing / Indoor Navigation → RSS measurements

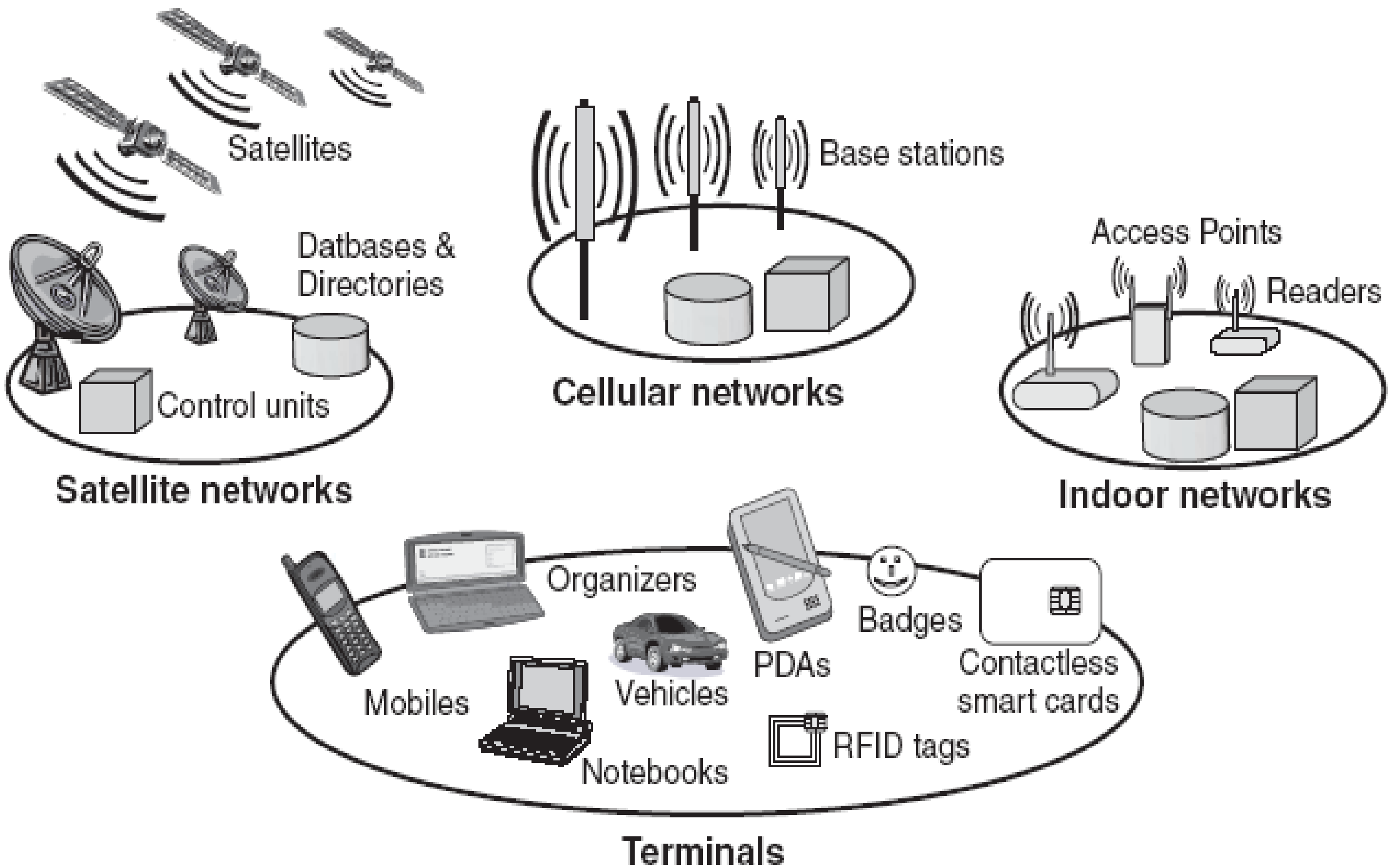
2.1 Positioning Fundamentals – Reference Systems

- Goal of positioning: **derive the geographic position** of a target with respect to a **spatial reference system**
- Spatial reference system
  - Coordinate system (Ellipsoidal/Cartesian)
  - Geodetic Datum
  - Projection (if location is to be represented on a map)





2.2 Positioning Fundamentals - Infrastructures



3. Global Satellite Positioning Systems in the past

- Russian satellite **Sputnik** was launched in 1957
  - Tremendous advance the connection of the various geodetic world datums.
  - Worldwide triangulation program (BC-4): simultaneously photographing reflective satellites by several sites separated by some 4000 km
  - **Doppler shift** in the signal broadcast by a satellite could be used to determine exact time of closest approach. Together with the ephemerides this leads to precise position anywhere in the world.
- Navy Navigation Satellite System (NNSS), also called **TRANSIT** (1960)
  - Predecessor of GPS
  - Six satellites / 1100km altitude
  - Primarily for vessel and aircraft positioning
  - 1 meter accuracy if point was occupied for several days
  - A satellite passed overhead only every 90 minutes

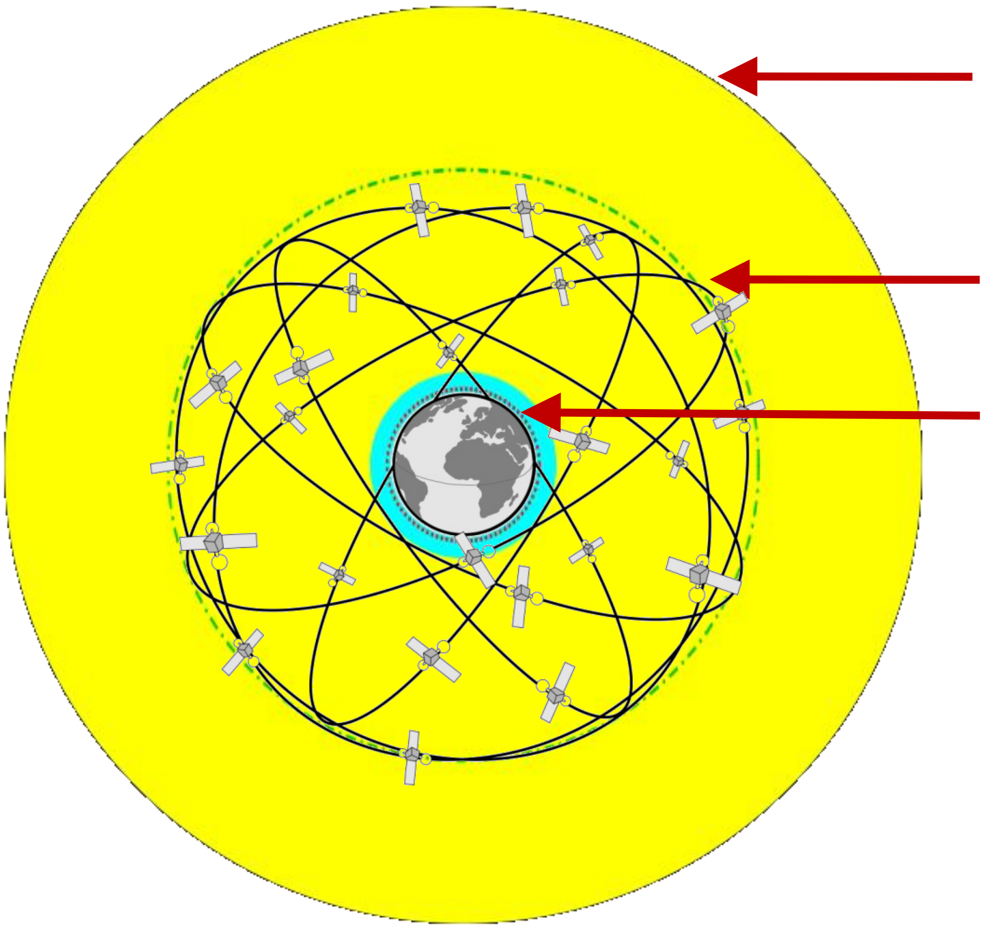
3. GPS – Mission Goals

- Defined by the US Department of Defense (DoD), developed to replace the TRANSIT system and to **deliver not only position**, but **also accurate time and speed**.
- Initial goals
  - User receiver cost < 10.000 $ and „5 bombs in the same hole“
  - Positioning **anywhere**, **continuously** & **in all weather conditions**
- Services
  - **Standard positioning service** (SPS) open to civil users, but single-frequency with **L1 coarse/acquisition signal** 1575.42 MHz, i.e. no ionosphere effect correction
  - **Precise positioning service** (PPS), dual-frequency, using P(Y) signals in **L1 and L2** (1227.60 MHz) bands, with military control access (key for pseudo-code)

GPS - History

1973	Decision to develop satellite navigation system
1978-1985	11 Block-I satellites launched
1989	First Block-II satellite launched
Dec 1993	Initial Operational Capability (IOC)
Mar 1994	Last Block-II satellite
July 1995	Full Operational Capability (FOC)
May 2000	Deactivation of **Selective Availability**
Sep 2005	First IIR-M GPS satellite

GPS – Orbital positioning



Geostationary Orbit, e.g., Communication, TV, Meteorologie (ca. 36.000 km)

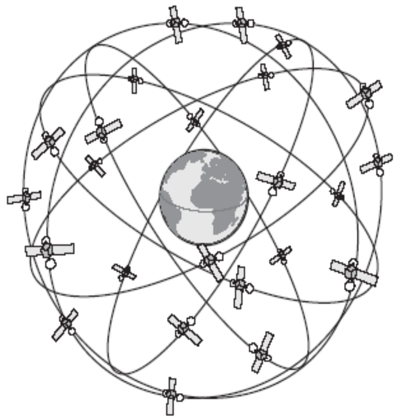
MEO: Medium Earth Orbit, e.g., **GPS satellites** (ca. 20.200 km)

LEO: Low Earth Orbit, e.g., ISS (ca. 700 km)

GPS - Satellites

- Block-I
  - Weight: 845 kg; Lifespan: **4.5 years**;
  - Energy: Solar panels (400W); Nickel-Cadium batteries
  - Out of order since 1996
- Block-II/-IIA
  - Weight: 1500kg; Lifespan: **7.5 years**; Wingspan: 5.1m
  - **Four atomic clocks** (2 rubidium, 2 cesium)
- Block-IIR
  - Weight: 2000kg; Costs: 75 million USD
  - **Three atomic clocks** (all rubidium clocks)
  - **Second civil signal** (L2C)
  - **New military signal with new code**
- Block-IIF
  - **Third frequency for civil use** (L5)

GPS – Components



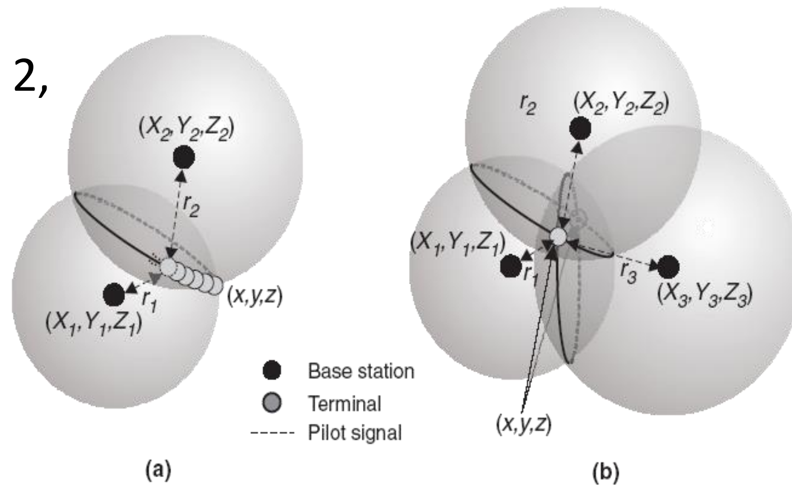
- Space segment
  - **24 satellites** circulating the Earth every 12 sidereal hours **on six orbits**
  - Each satellite is equipped with onboard atomic clocks
  - Orbits are equally spaced 60° apart from each other with an inclination angle of 55° to the equator
  - Orbit altitude: approx. 20,180 km

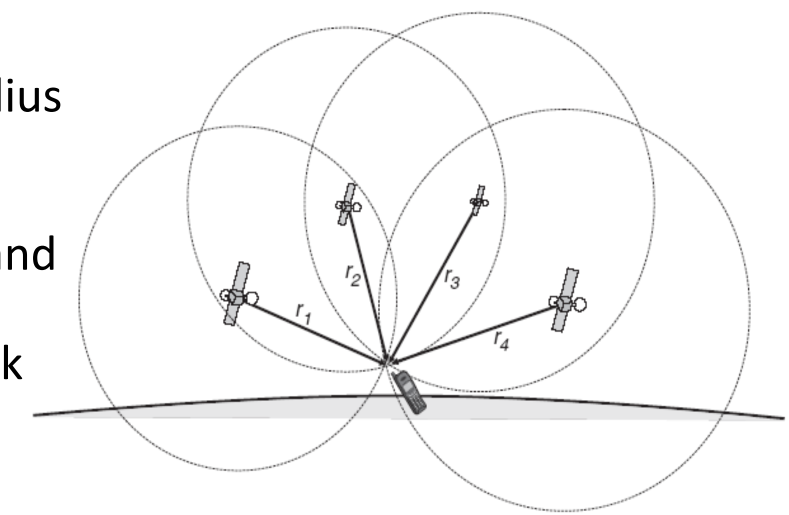
- Control segment
  - Initially: **Five ground** stations for monitoring and controlling the satellites
  - In 2005: **Six additional** monitoring stations
  - **Adjust or synchronize satellites**

- User segment
  - GPS receiver
  - Applications: land, sea, and air navigation, as well as military purposes and location-based services

GPS – circular trilateration

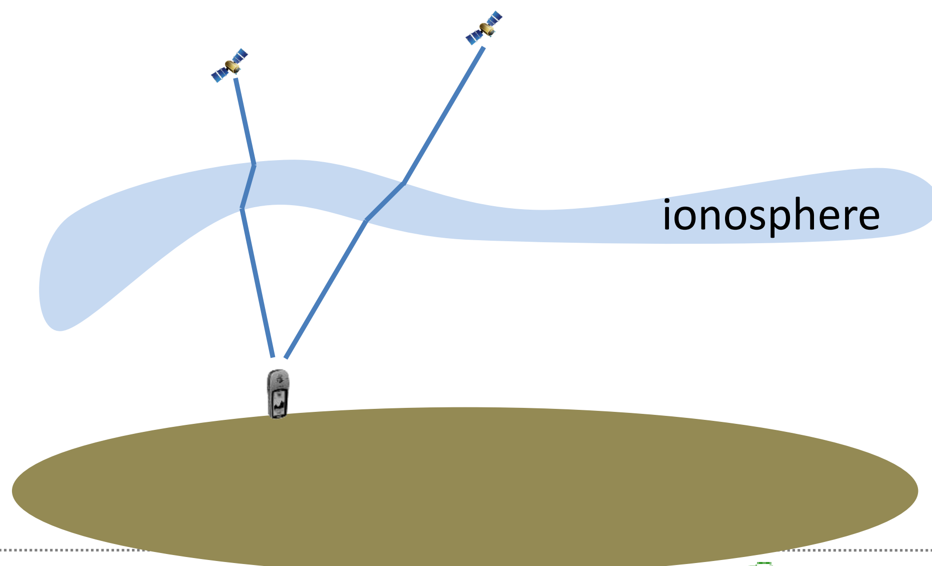
- **Known:**
  - Position $p_i = (x_i, y_i, z_i)$ for satellites $i \in \{1, 2, 3, 4\}$ at time t_i
  - Inaccurate reception time tr_i
  - Speed of light c
- **Unknown:**
  - Position p
- **Calculation:**
  - $r_i = (tr_i - t_i) * c$ for i = **1,2,3**
  - Estimate position p_{est} : intersection of spheres (centered on satellite i with radius $r_{i)}$
  - P_{est} contains the coordinates (x,y,z), determined on basis of the signals 1,2 and 3
  - P_{est} is **not accurate** due to different clock times at the satellites and the receiver
  - Signal 4 is now used to determine the corrected reception time ***t***





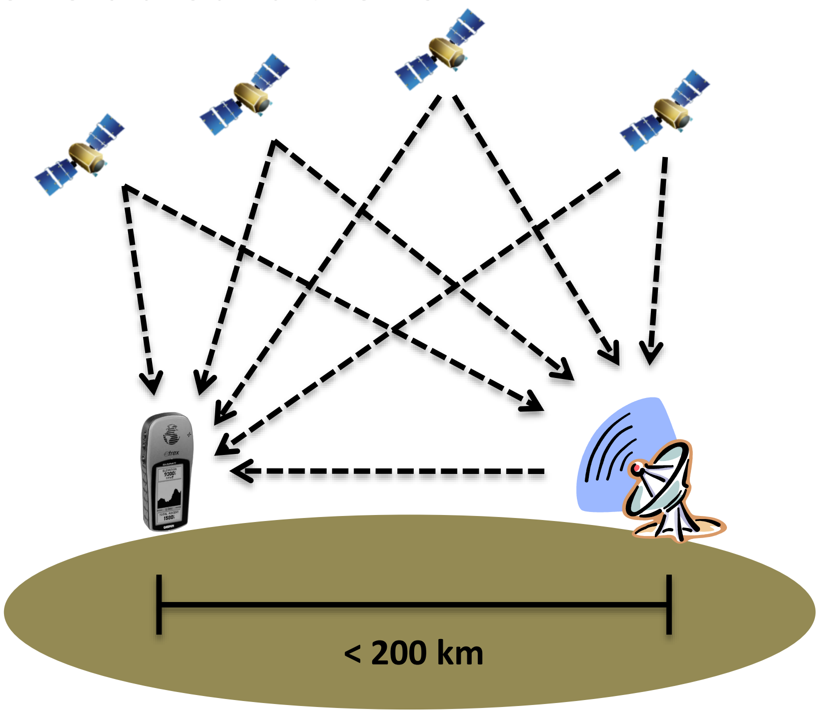
GPS - Possible Error Sources

- Satellite clocks (although four highly accurate atomic clocks) can cause **time error** of 10ns
- **Satellite position** is only known up to approx. 1-5m
- **Receiver** has only limited accuracy
- **Multipath propagation**
- **Satellite geometry** (Dilution Of Precision, DOP)
- Signal (speed of light) slow down when crossing **ionosphere** and **troposphere**

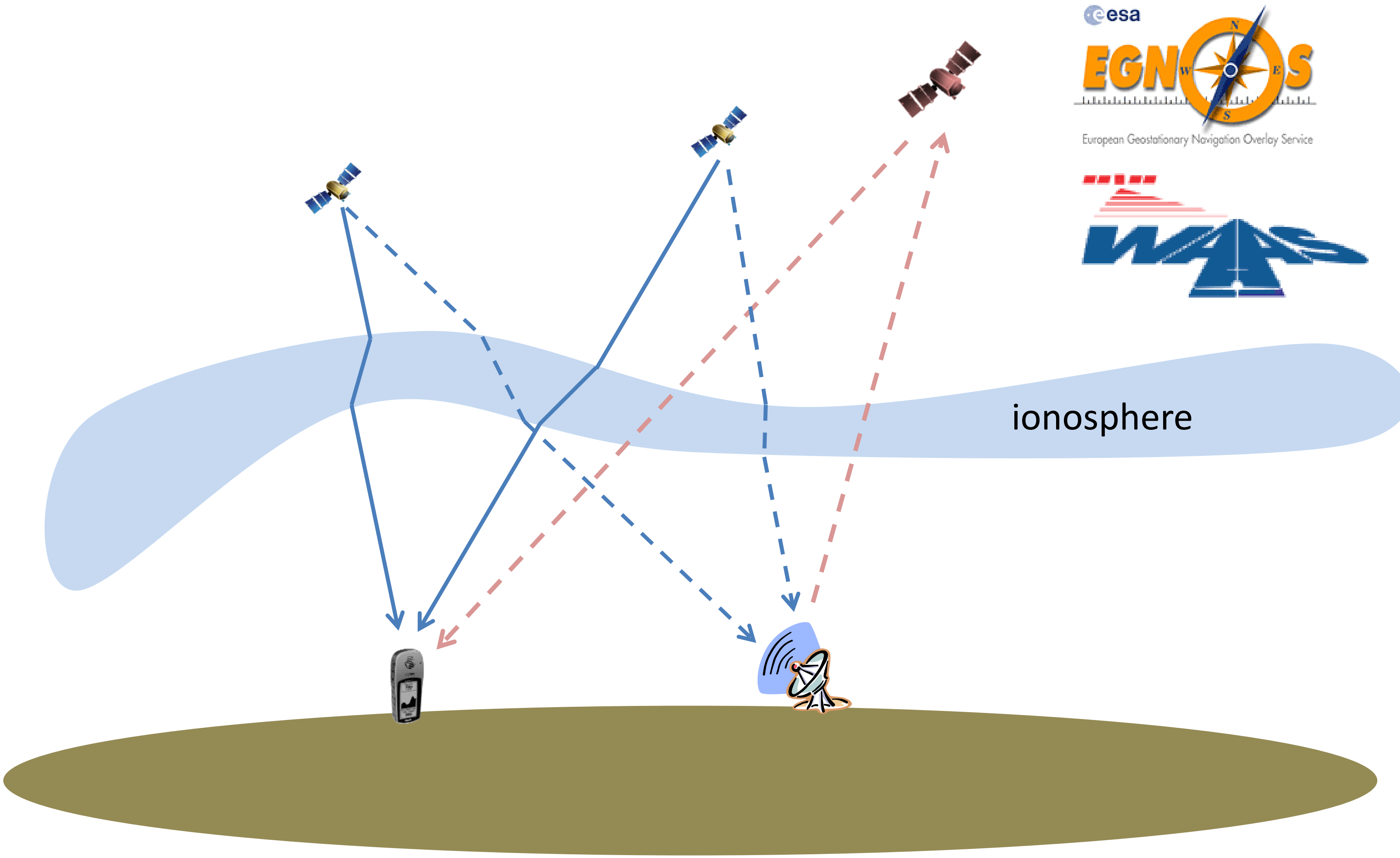


GPS – differential GPS (DGPS)

- Reference station (RS) located at a known and accurately surveyed point
- RS determines its GPS position using four or more satellites
- Deviation of the measured position to the actual position can be calculated
- Variations are valid for all the GPS receivers around the RS
- Corrections are transmitted by radio



GPS - Satellite-based Augmentation Systems



4. Galileo

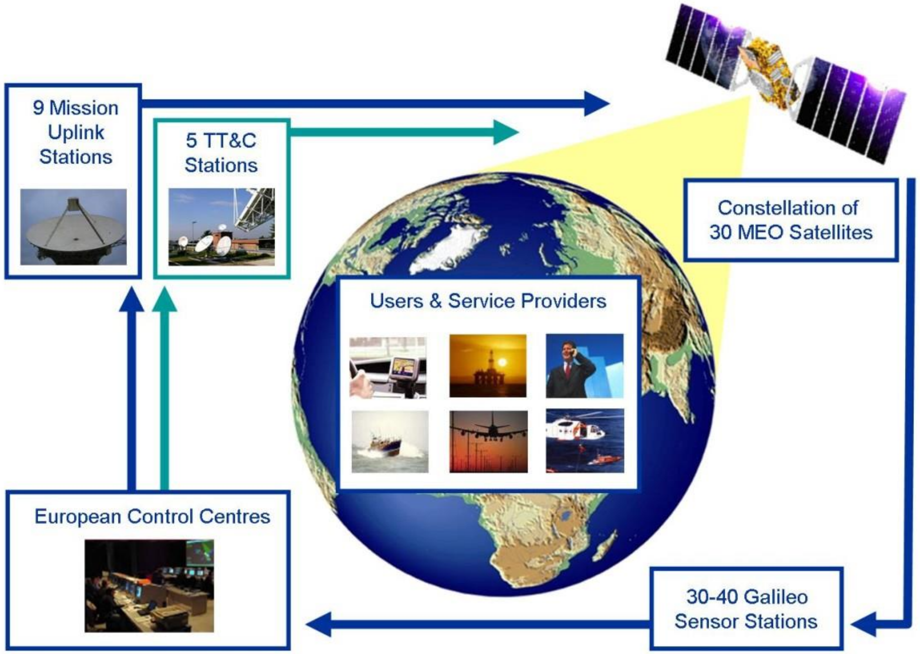
- European GNSS
- Publicly available since December 2016
- Independence of other systems
- **More services**: Open Service, Commercial, Safety-of-Life, Public Regulated, Search-and-Rescue
- Advantages
  - **Precision**: Combination of GPS and Galileo in dual receivers will lead to higher precision
  - **Availability**: Higher number of satellites will improve the availability.
  - **Coverage**: Galileo will also provide a better coverage at high latitudes due to the location and inclination of the satellites.

Galileo – Operation

- The Galileo program is structured in two phases
  - **In-Orbit Validation (IOV) phase**
    - **Qualifiying and validating** the systems through in-orbit tests
    - Two experimental satellites: Dec 2005, Apr 2008
    - Four operational satellites: Q3/4 2011, Q1/2 2012
  - **Full Operational Capability (FOC) phase**
    - Deployment of remaining ground and space infrastructure
    - Intermediate initial **operational capability: 18 satellites** in operation (since December 2016)
    - **Full system**: **30 satellites**, control centers located in Europe and a network of **sensor stations** and **uplink stations** installed around the globe

Galileo – Architecture

- 30 satellites in MEO: Each satellite will contain
  - a navigation payload
  - search and rescue transponder
- 30-40 sensor stations
- 3 control centers
- 9 Mission Uplink stations
- 5 TT&C stations.



http://ec.europa.eu/enterprise/policies/satnav/galileo/programme/index_en.htm

5. Other GNSS

- Global Navigation Satellite System (**GLONASS**)
  - System currently operated by the Russian Defense Ministry
  - 24 planned satellites, started since 1982
  - 3 orbital levels
  - Orbital altitude of 19,100 km
  - Full operation since 1996

- Compass Navigation Satellite System (CNSS)
  - China’s second-generation satellite navigation system (also known as **BeiDou 2**)
  - Long-term goal: Develop a global navigation satellite network **similar to the GPS and GLONASS**
  - 25~35 satellites: 4 GEO satellites and MEO satellites
  - There will be two levels of positioning service: Open and restricted (military)
  - Coverage: Initially only neighboring countries, later on extension to global navigation satellite system.
  - Launches: 1 MEO (Apr 07) and 3 GEO (Apr 09 – June 10)

Outdoor Positioning Systems - Practical

- Assignment
  - GPS-based applications
  - Coordinate transformation (using on maps)