LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Praktikum Mobile und Verteilte Systeme

Outdoor Positioning

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http://www.mobile.ifi.lmu.de

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Outdoor Positioning

Today:

1. **History of Positioning**
2. **Positioning Fundamentals**
3. **GPS – Global Positioning System**
   – System architecture
   – Positioning via GPS
4. **Galileo**
   – System architecture
   – Enhancements and new services
5. **Other Global Navigation Satellite Systems (GNSS)**

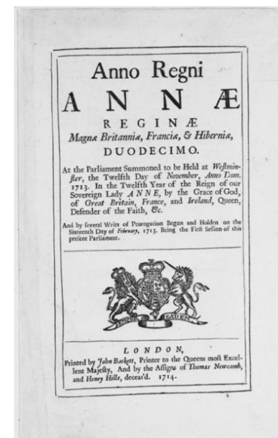
1. History of Positioning I

- **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), important for **longitude** determination
  – 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 sailors 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.



Anno Regni
A N N Æ
R E G I N Æ
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.

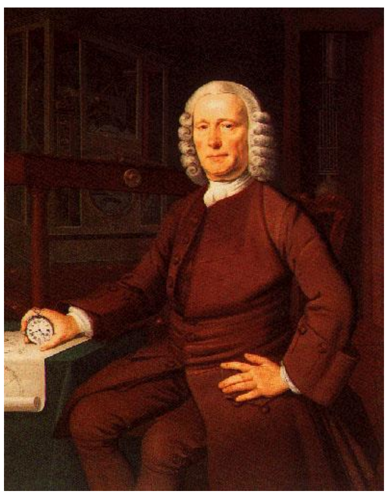
And by several Writs of Prorogation Begun and Holden on the Sixteenth Day of *February*, 1713. Being the First Session of this present Parliament.

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.

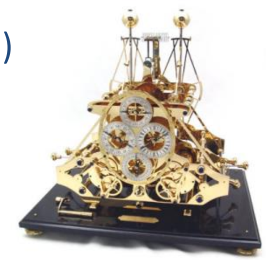
- Expected accuracy (drift):
  - Maximum error: **0,5 degrees**
  - 0,5 degrees **= 30 nautical miles** at the equator
    = motion during 2 minutes of earth rotation
    = 3 seconds per day during 40 days
    (40 days = a 6 week journey from England to the West Indies)

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 (1735)
1,2m
34 kg



H2 (1741)

H3 (1757)

H4 (1761)
13cm
1.45 kg

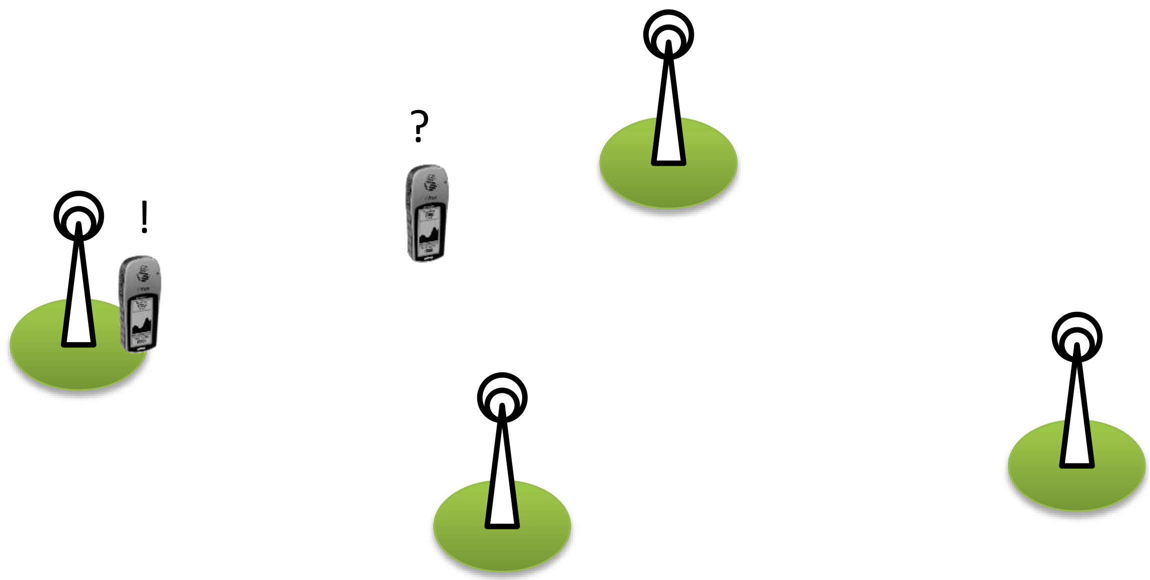
2. Positioning Fundamentals – Components

- 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** and **sensors**: Gyroscope Accelerometer Odometer
Pattern matching or learning algorithms	Visual images or fingerprints	e.g., via Camera or Received signal strength

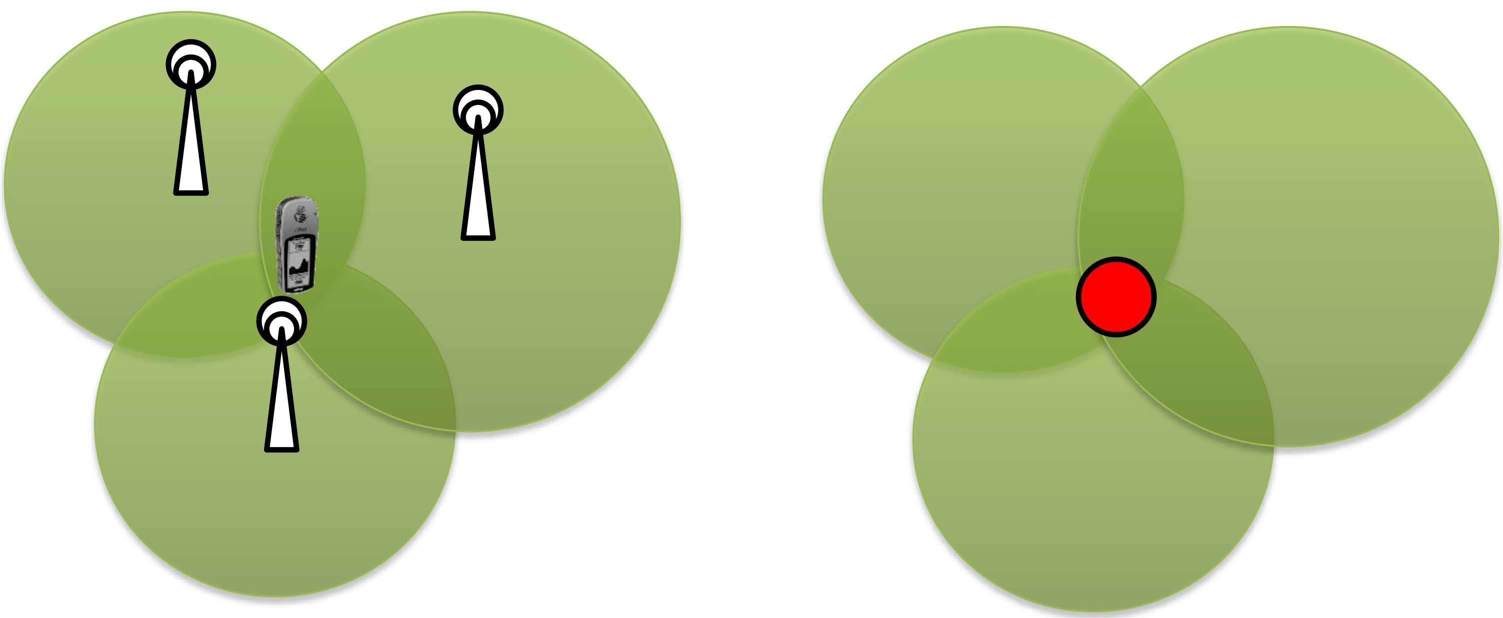
Proximity Sensing

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



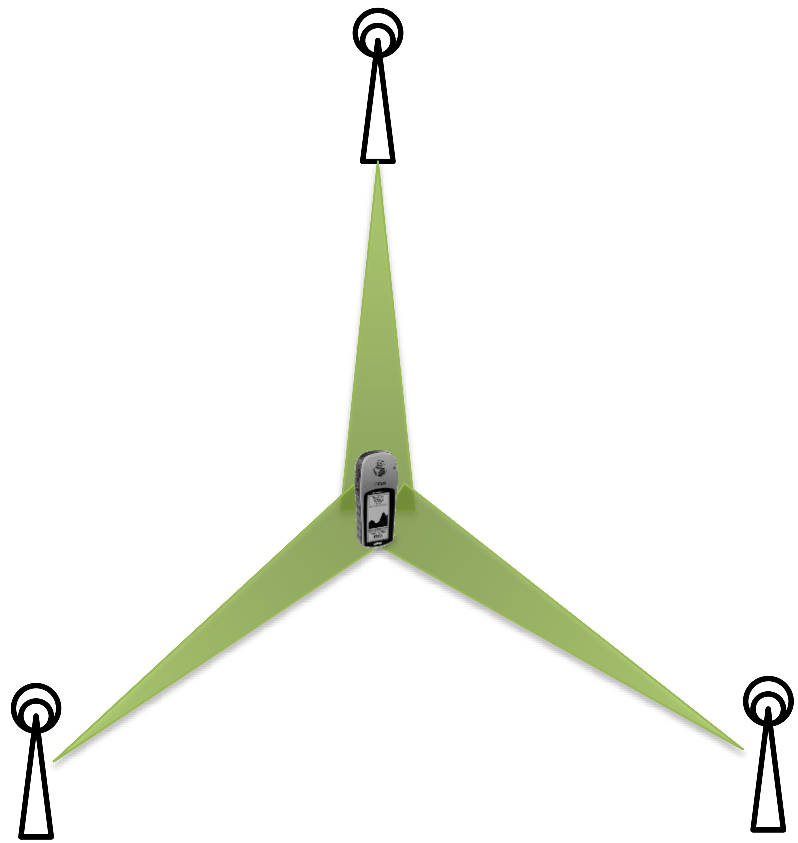
Lateration

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



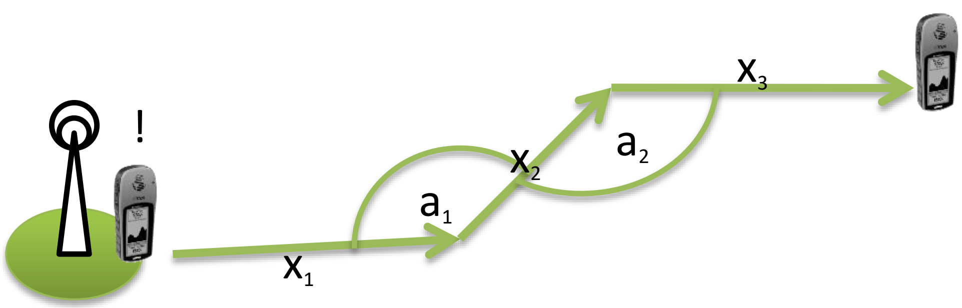
Angulation

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



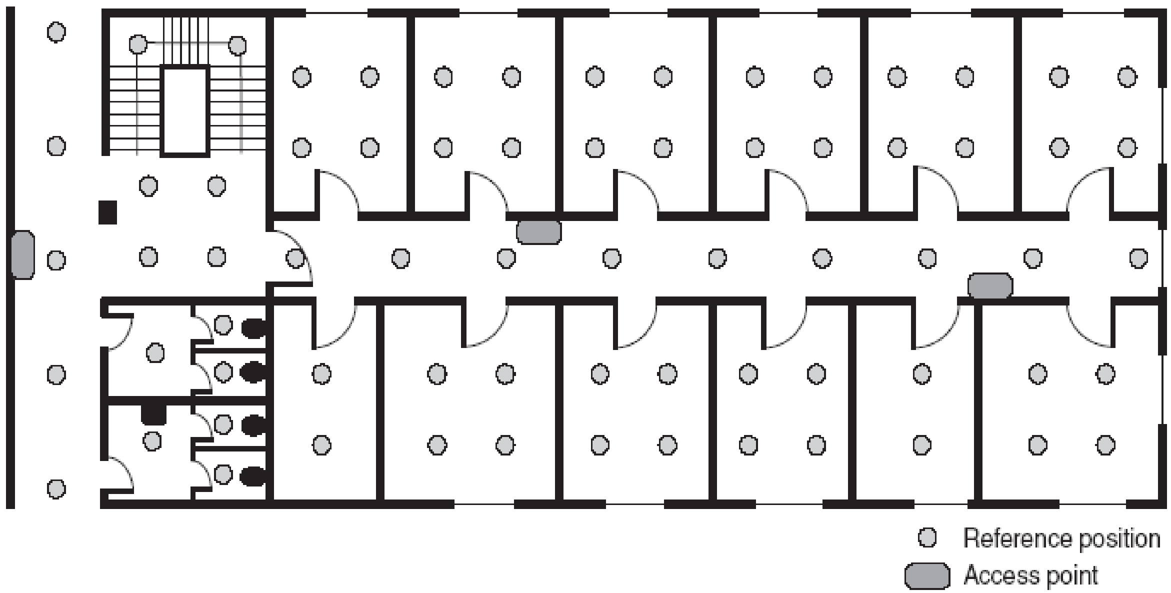
Dead Reckoning

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



Fingerprinting

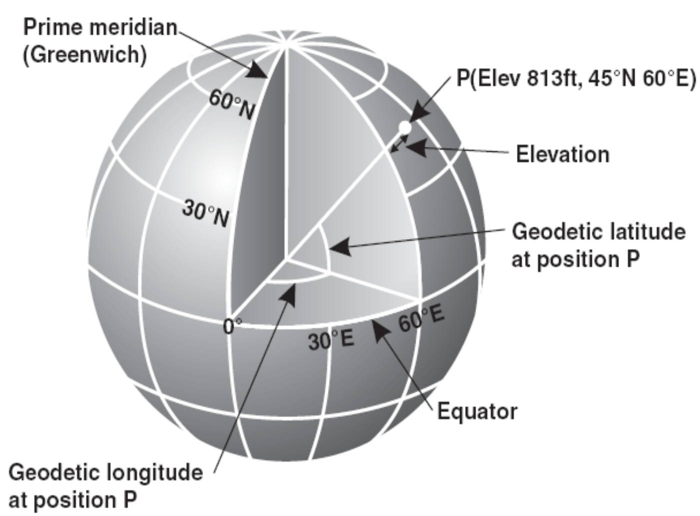
- Position is derived by the comparison of location dependent online measurements with previously recorded data:

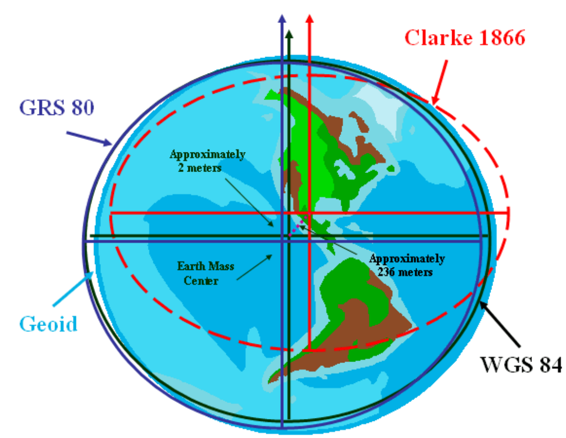


- Indoor Navigation / Fingerprinting via RSS measurements

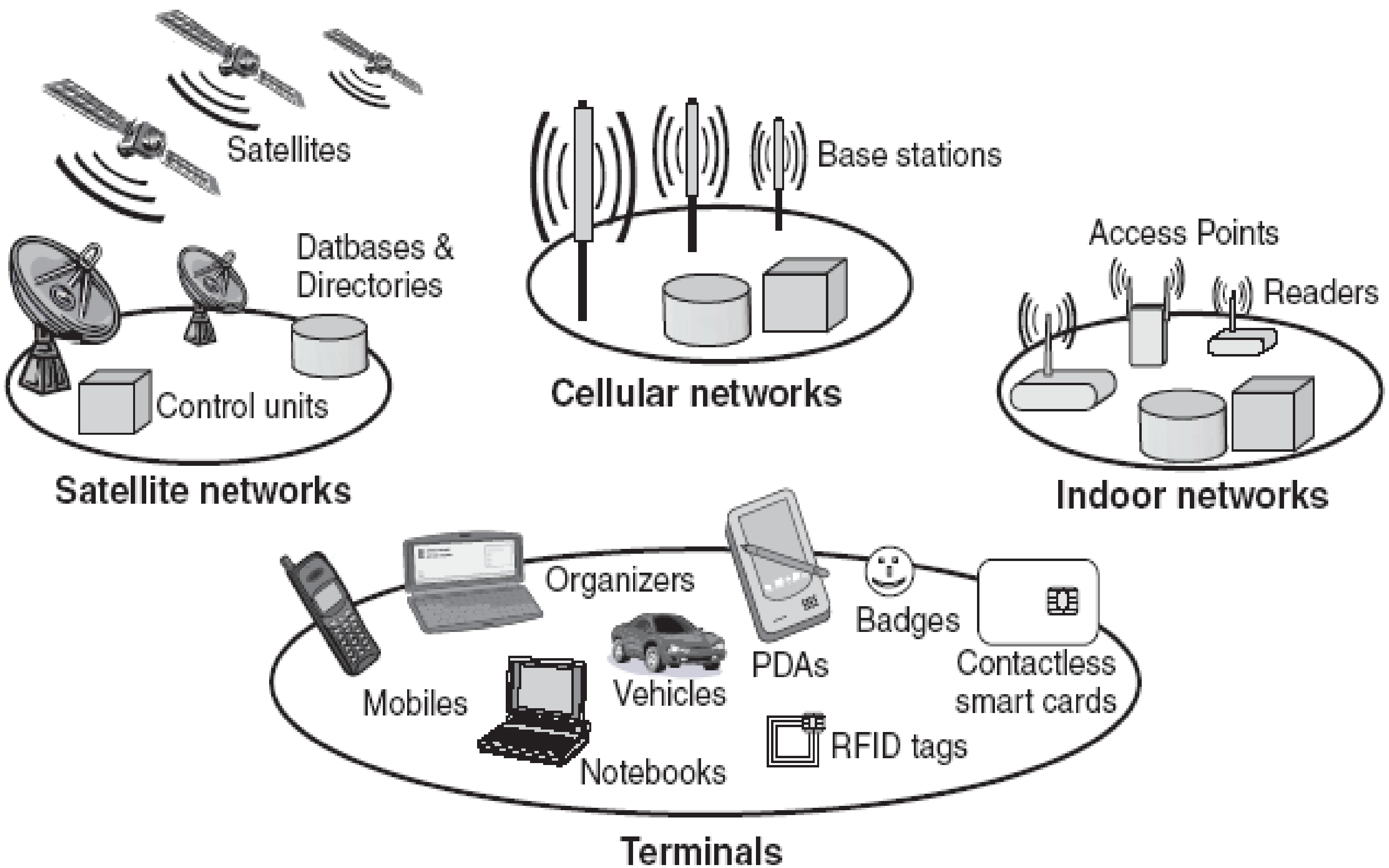
2.1 Positioning Fundamentals – Reference Systems

- Goal of positioning: **derive the geographic position** of a target with respect to a **spatial reference model**
- Spatial reference model
  - Coordinate system (Ellipsoidal/Cartesian)
  - Geodetic datum, e.g., WGS-84
  - Projection (if location is to be represented on a map), e.g., Mercator projection





2.2 Positioning Fundamentals - Infrastructures



3. Global Satellite Positioning Systems in the past

- Russian satellite **Sputnik** launched in 1957
  - Proof of the ability to **track artificial objects in space** via short wave radio signals
  - **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 positioning anywhere in the world.
- Navy Navigation Satellite System (NNSS), also called **TRANSIT**
  - Predecessor of GPS
  - Six satellites / 1100km altitude
  - Primarily for vessel and aircraft positioning
  - **1m accuracy** if point was **occupied for several days**
  - A satellite passed overhead only **every 90 minutes**

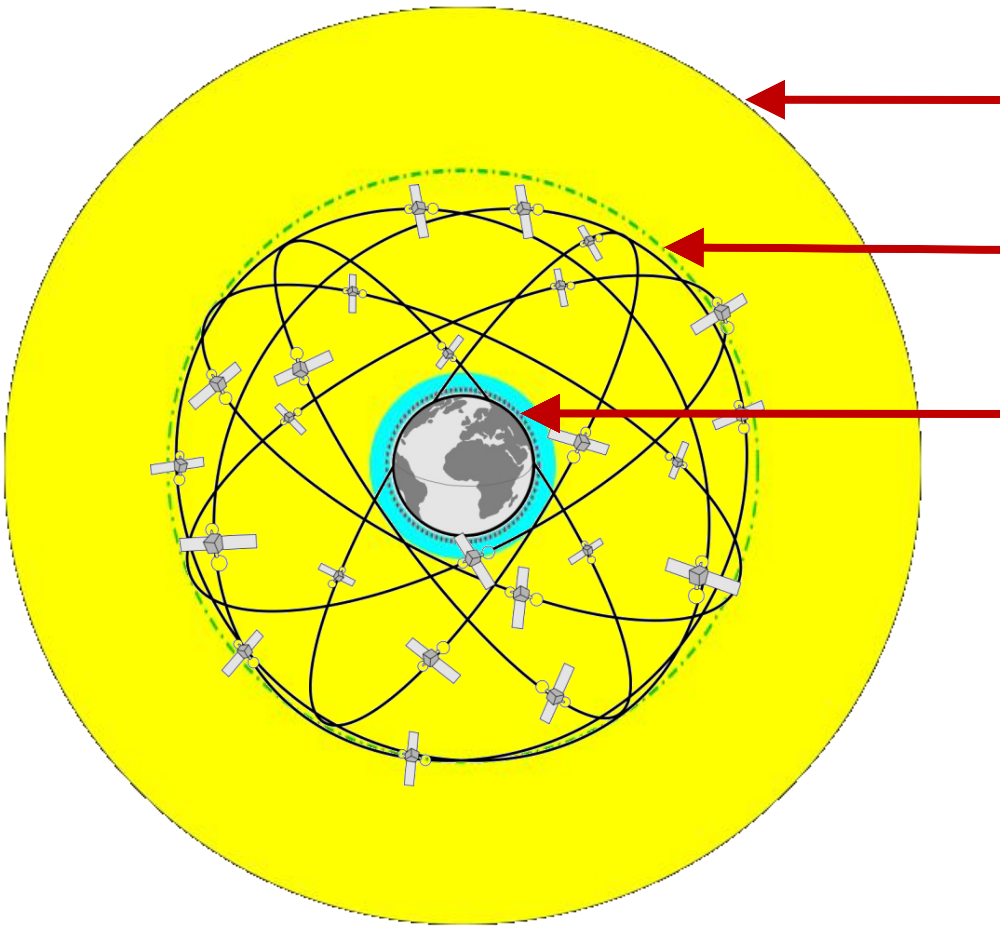
3. GPS – Mission Goals

- 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, **selective availability**
  - **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)

3.1 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

3.2 GPS - Satellites



Geostationary orbit (ca. 36.000 km)
communication, TV, and meterology

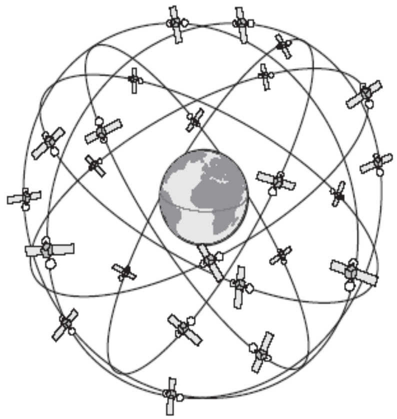
MEO: Medium Earth Orbit
e.g., **GPS satellites** (ca. 20.200 km)

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

3.2 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)

3.3 GPS – Components



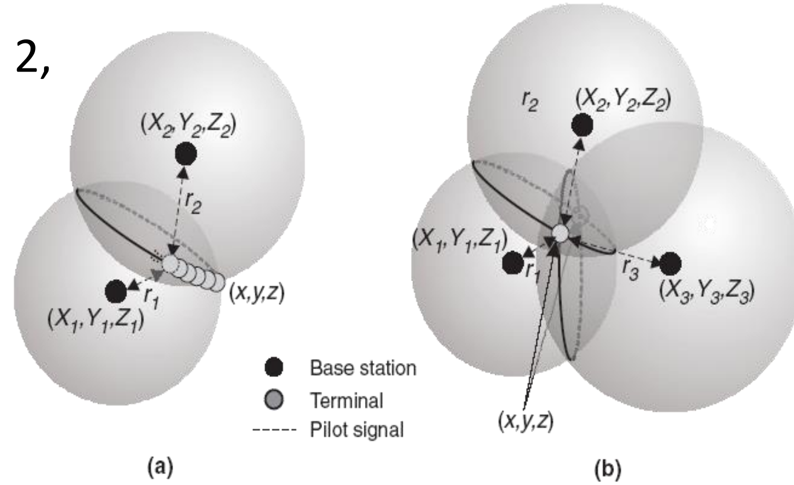
- Space segment
  - **24 satellites** circulating the Earth every 12 sidereal hours on six orbits
  - Each satellite is equipped with onboard atomic clocks
  - Orbits are equally spaced **60° apart from each other** with an inclination angle **of 55° to the equator**
  - Orbit altitude: approx. 20,180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

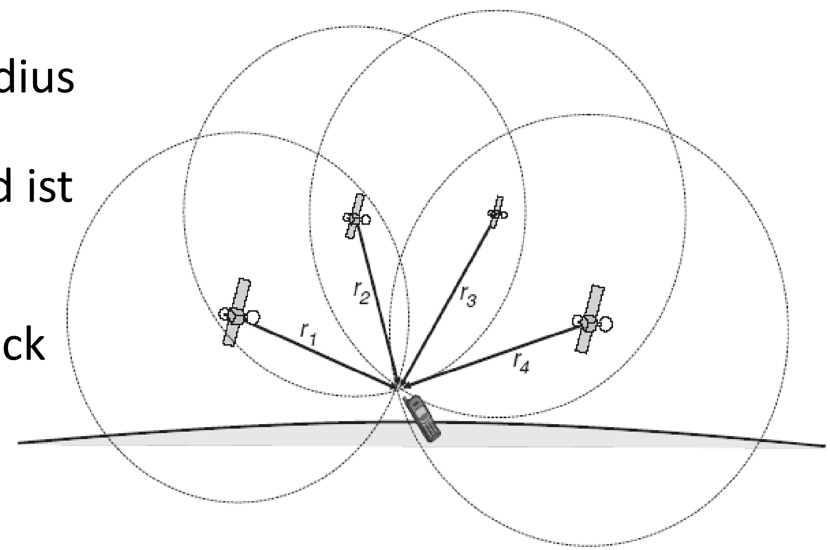
- Control segment
  - Initially: **Five ground** stations for monitoring and controlling the satellites
  - In 2005: **Six additional** monitoring stations
  - **Adjust or synchronize satellites**

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

3.4 GPS – Circular Lateration

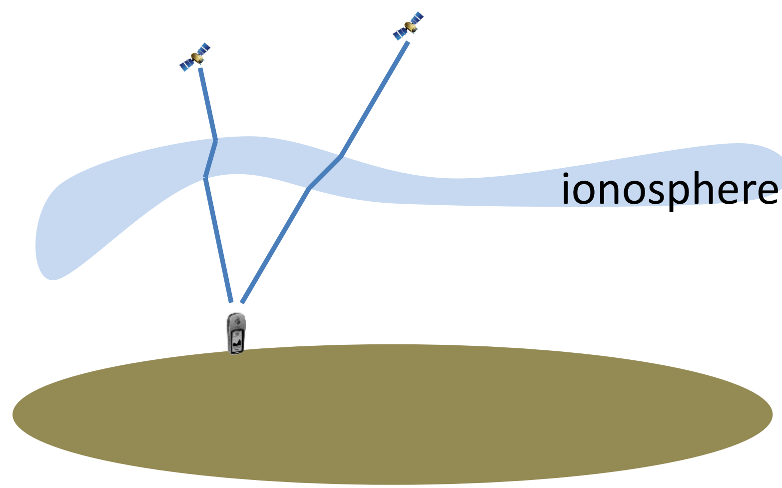
- **Known:**
  - Position $p_i = (x_i, y_i, z_i)$ for satellites $i \in \{1, 2, 3, 4\}$ at time t_i
  - Inaccurate reception time tr_i
  - Speed of light c
- **Unknown:**
  - Position p
- **Calculation:**
  - $r_i = (tr_i - t_i)*c$ for i = **1,2,3**
  - Estimate position p_{est} : intersection of spheres (centered on satellite i with radius $r_{i)}$
  - p_{est} contains the coordinates (x,y,z) and ist 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***





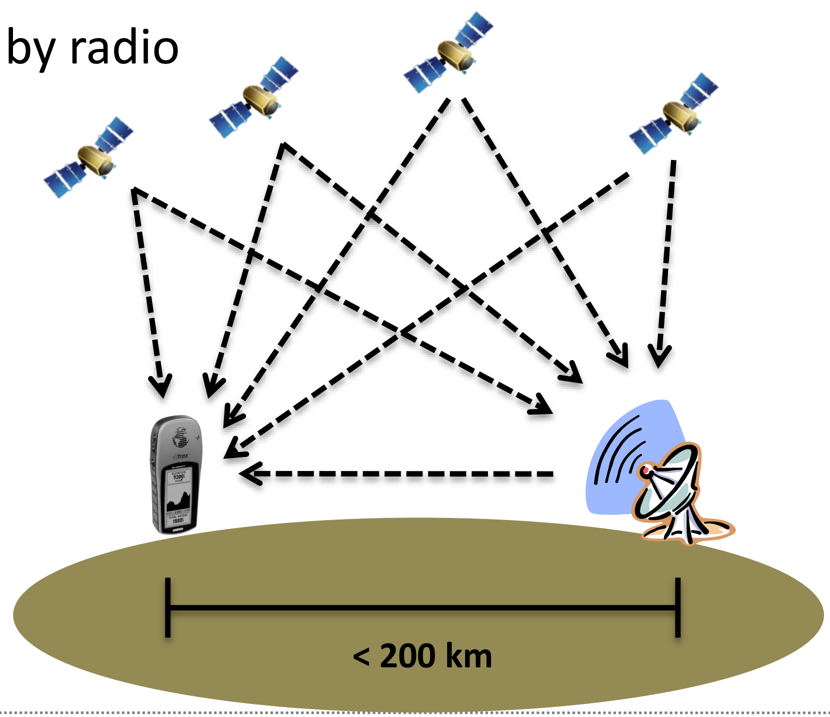
3.5 GPS - Possible Errors

- **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**

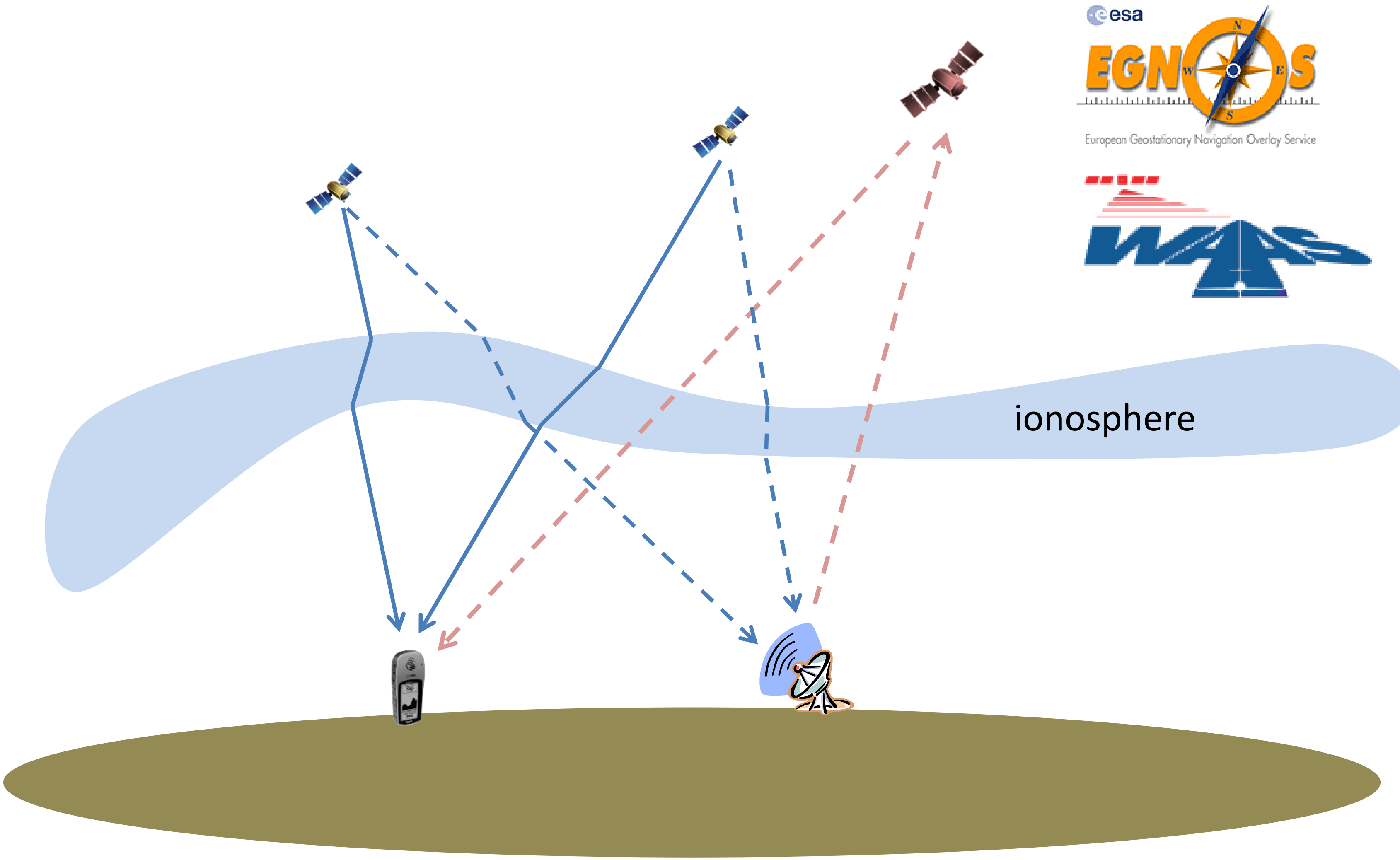


3.6 Differential GPS (DGPS)

- **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
- Runtime corrections are transmitted by radio



3.7 Satellite-based Augmentation Systems



4. Galileo

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

4.1 Galileo – Services

- **Open Service**
  - basic signal provided free-of-charge
- **Safety-of-Life Service**
  - Enhanced signal including an **integrity function** that will **warn** the user within a few seconds in case of a **malfunction**. This service will be offered to the safety-critical transport community, aviation, etc.
- **Commercial Service**
  - combination of two encrypted signals for higher data throughput rate and higher accuracy authenticated data;
- **Public Regulated Service**
  - two encrypted signals with controlled access for specific users like governmental bodies; security against manipulation, availability garanties
- **Search And Rescue Service**
  - Galileo will contribute to the international COSPAS-SARSAT cooperative system for humanitarian search and rescue activities. Each satellite will be equipped with a transponder transferring the distress signal from the user to the Rescue Coordination Centre and informing him that his situation has been detected.

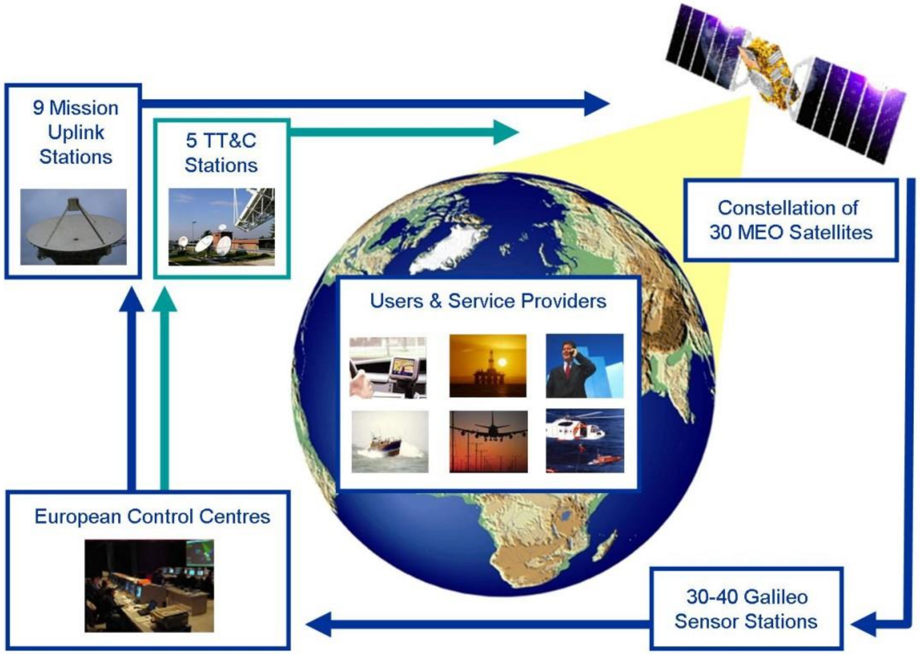
http://ec.europa.eu/enterprise/policies/satnav/galileo/programme/index_en.htm

4.2 Galileo – Operation

- Galileo programme 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
    - **Full system: 30 satellites**, control centers located in Europe and a network of **sensor stations** and **uplink stations** installed around the globe

4.3 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

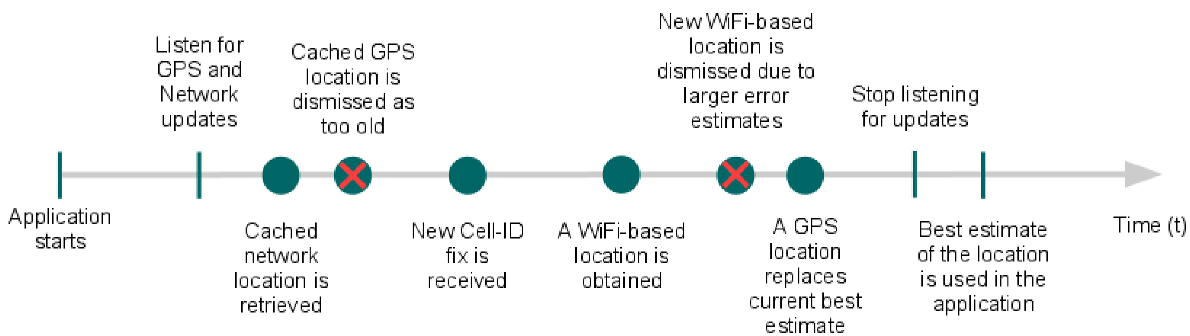
5. Other GNSS

- Global Navigation Satellite System (**GLONASS**)
  - Program started in 1982
  - System currently operated by the Russian Defense Ministry
  - 24 planned satellites
  - 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: Development of as system **similar to the GPS and GLONASS**
  - 25~35 satellites: **4 GEO satellites** and **MEO satellites**
  - 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)

Hands-on

- Create location-based applications with Android location services
  - Android Developer tutorials
    https://developer.android.com/guide/topics/location/strategies
  - Get familiar with typical challenges:
    - Multitude of location sources
    - User Movement
    - Varying accuracy
  - Applying an application process chain satisfying your application's individual needs (e.g., demands for accuracy or update-rate):



Source: https://developer.android.com/guide/topics/location/strategies