



LUDWIG-
MAXIMILIANS-
UNIVERSITÄT
MÜNCHEN

Praktikum Mobile und Verteilte Systeme

Outdoor Positioning Systems

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

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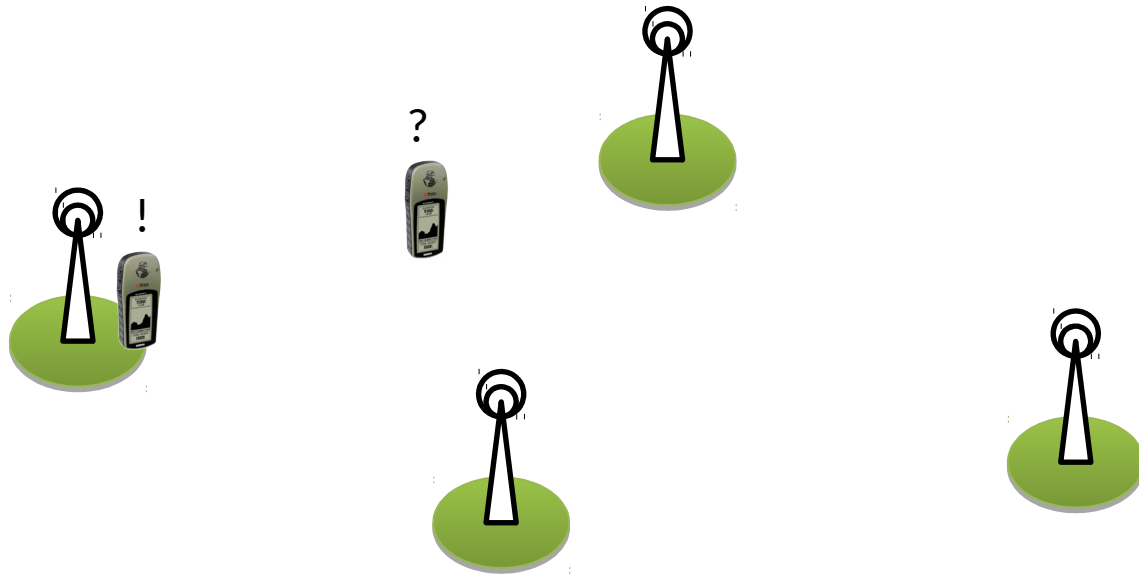
Outdoor Positioning Systems - Introduction

Today:

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

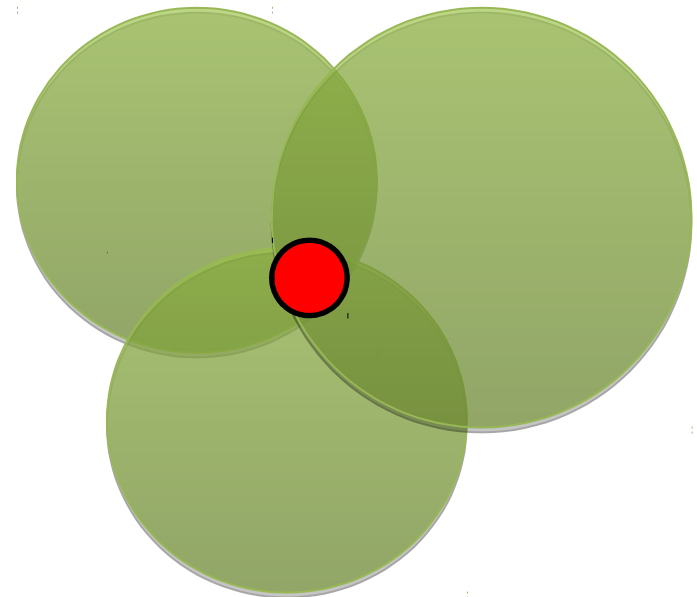
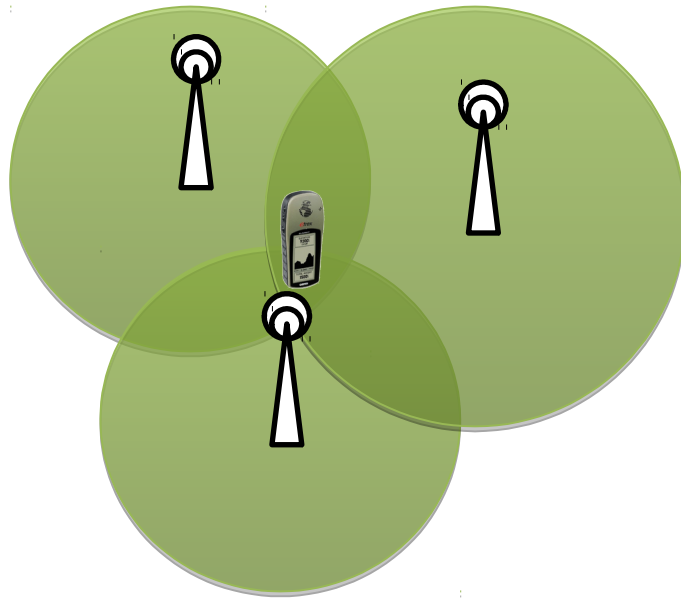
Proximity Sensing

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



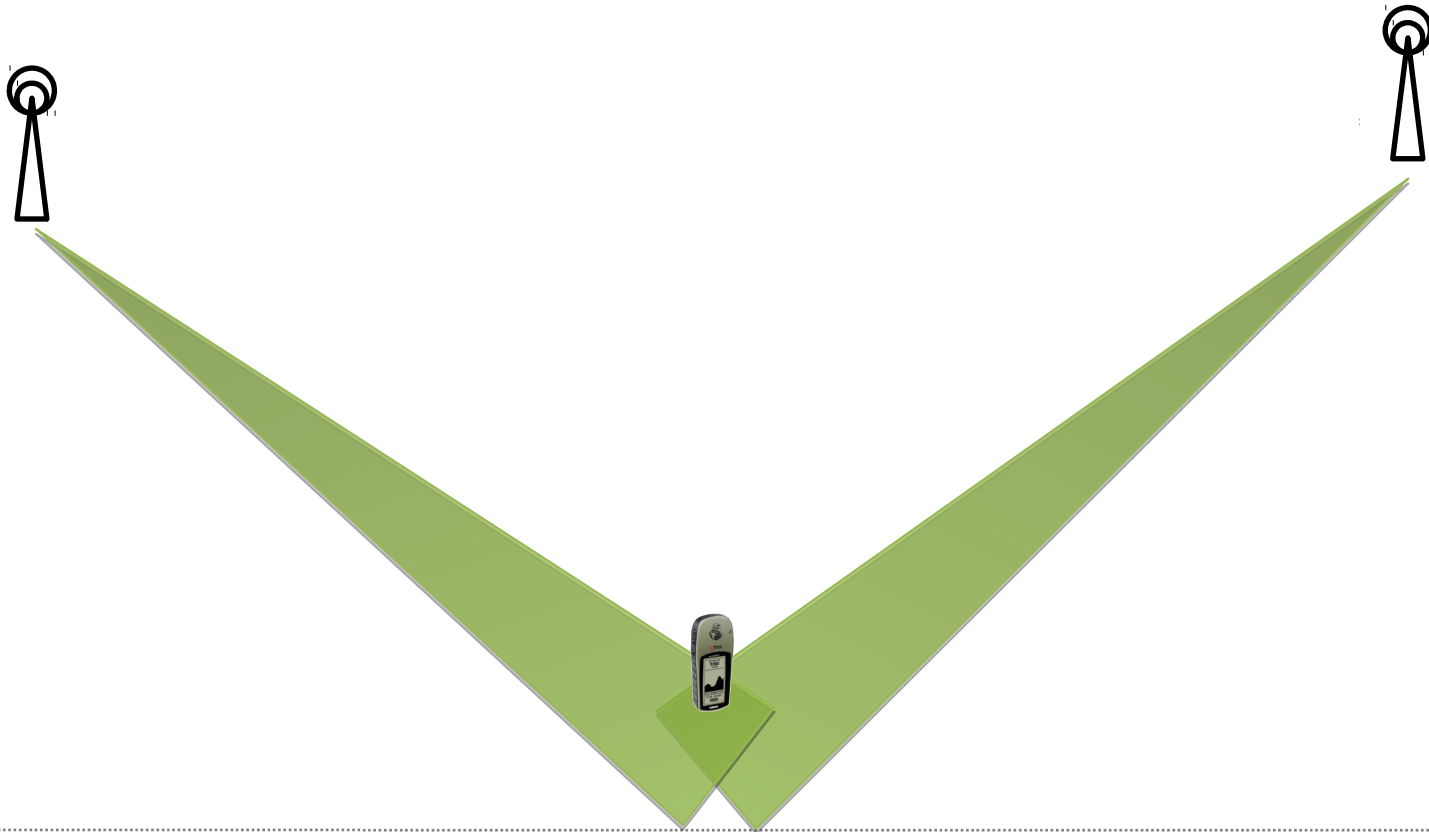
Lateration

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



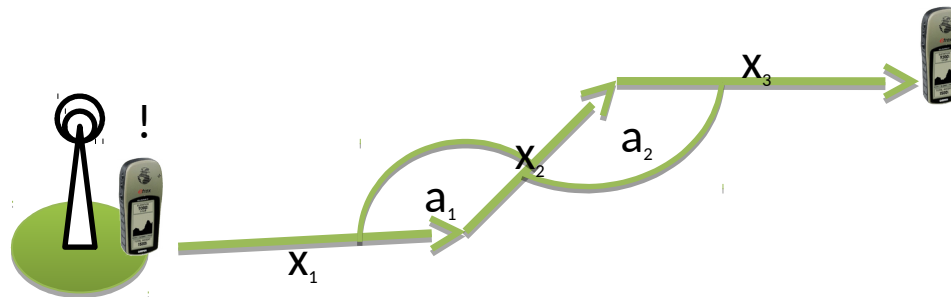
Angulation

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



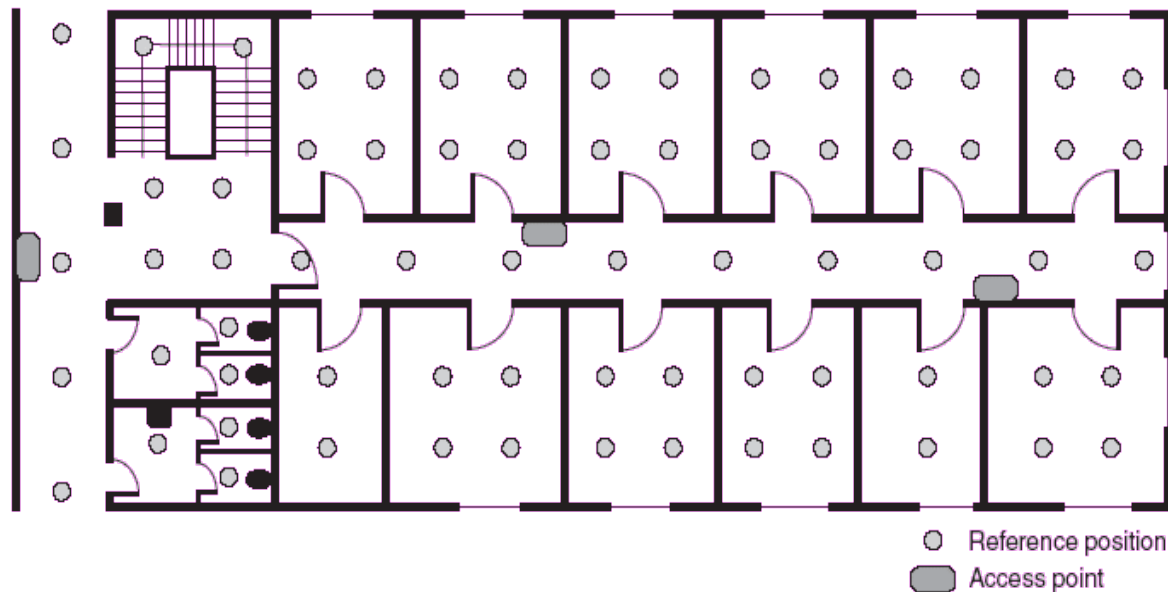
Dead Reckoning

- From a fixed starting position, the movement of the mobile device is estimated (e.g., using velocity and direction of movement):



Fingerprinting

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



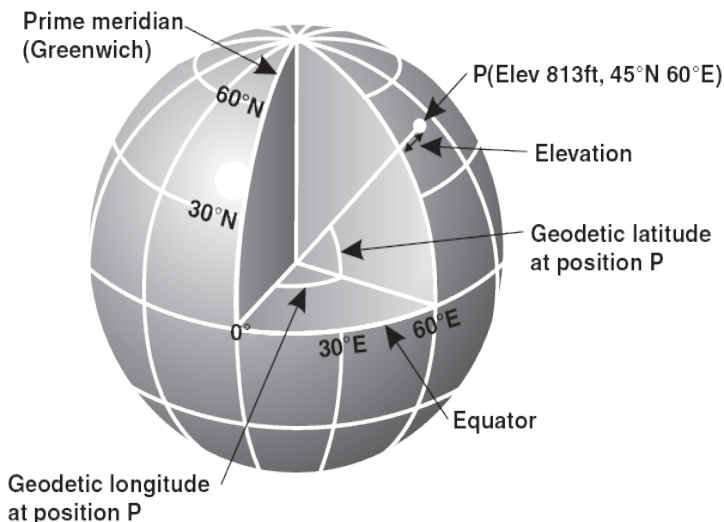
1. Positioning Fundamentals – Components

- 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

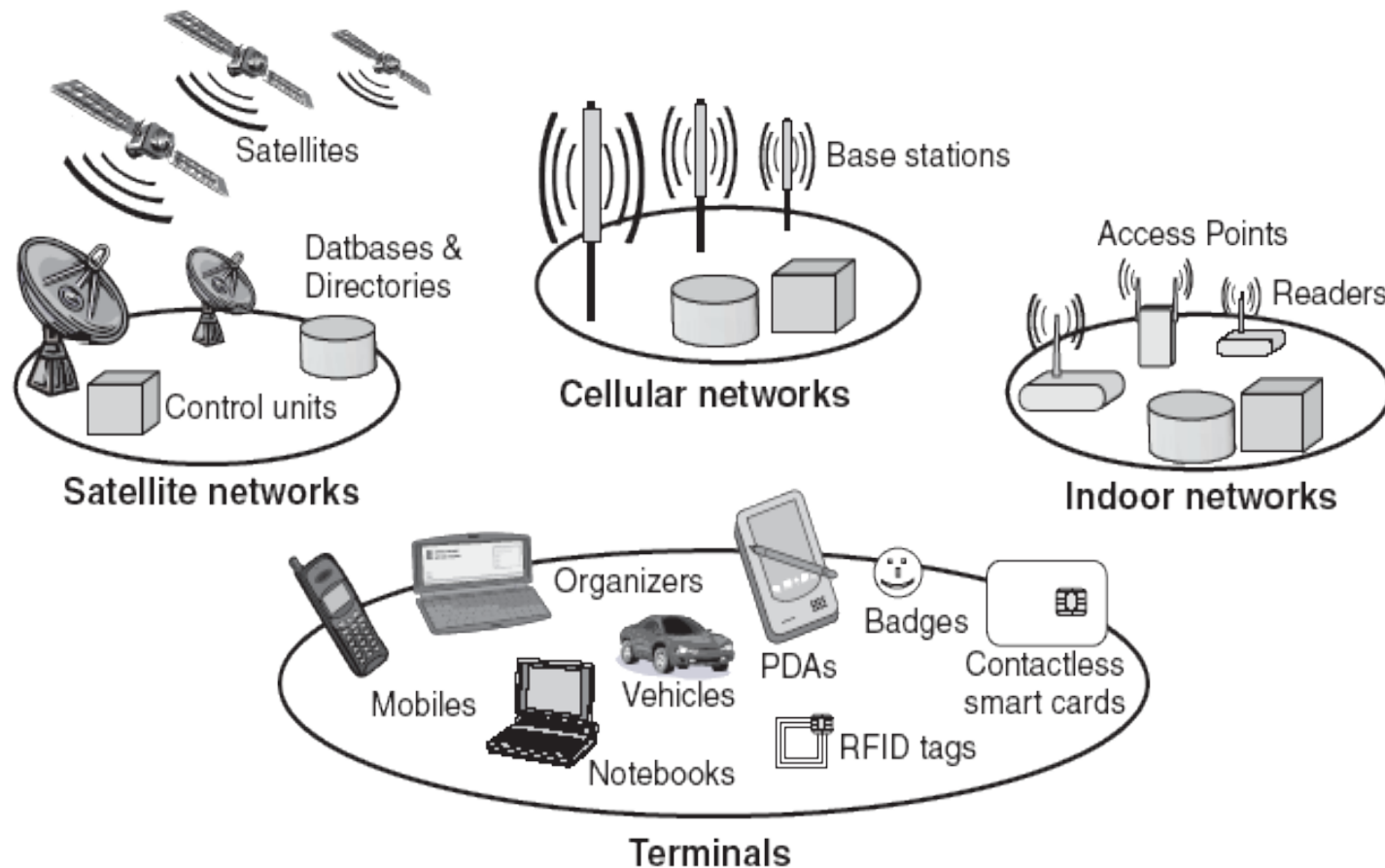
Positioning method	Observable	Measured by
Proximity sensing	Cell-ID, coordinates	Sensing for pilot signals
Lateration	Range or	Traveling time of pilot signals Path loss of pilot signals
	Range difference	Traveling time difference of pilot signals Path loss difference of pilot signals
Angulation	Angle	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

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)
 - 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** launched in 1957
 - tremendously advanced 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**
 - 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

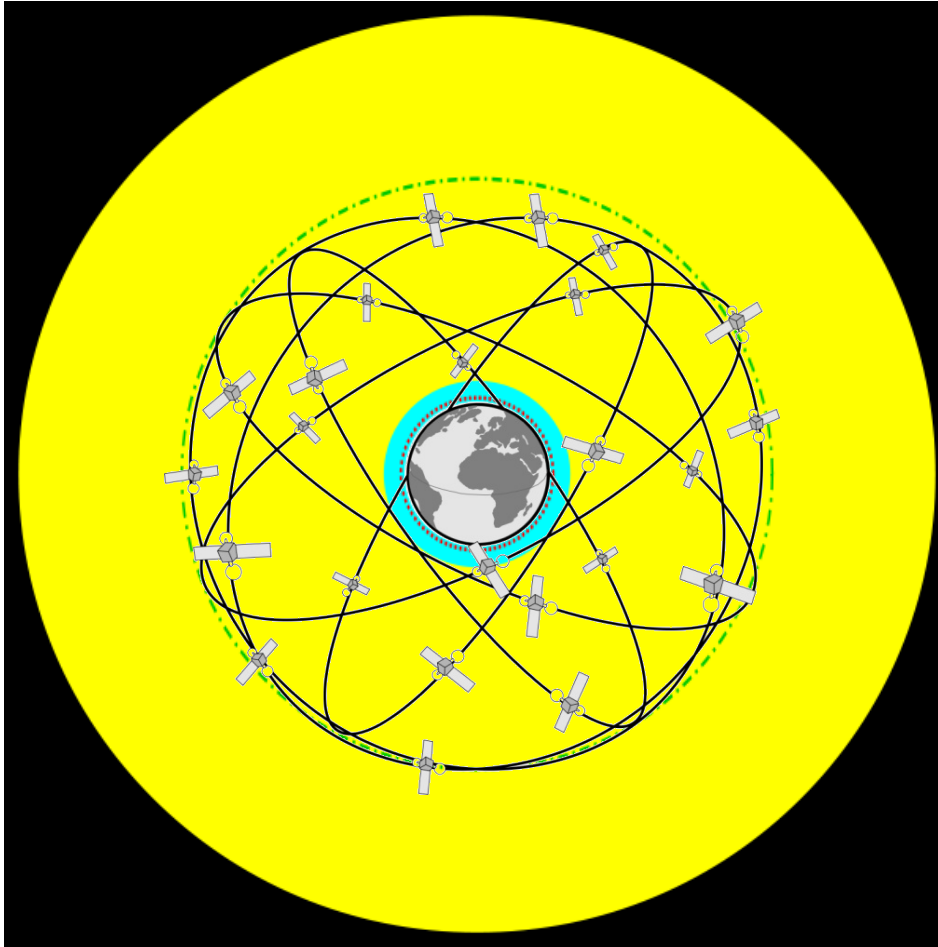
3. GPS – Mission Goals

- 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 \$
 - 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)

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)
Sep 2005	First IIR-M GPS satellite

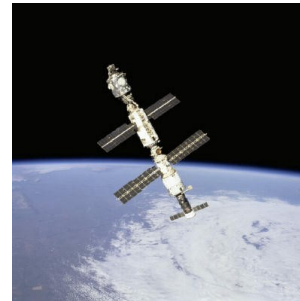
3.2 GPS - Satellites



Geostationary orbit (ca. 36.000 km)

GPS satellites (ca. 20.200 km)

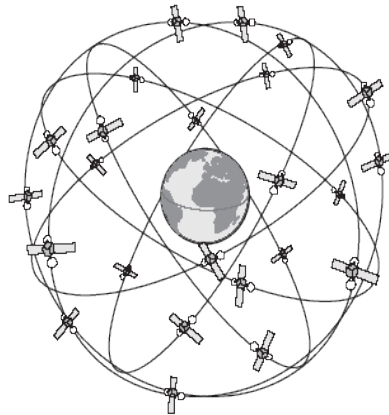
ISS (ca. 700 km)



3.2 GPS - Satellites

- Block-I
 - Weight: 845 kg; Lifespan: 4.5 years;
 - Energy: Solar panels (400W); Nickel-Cadium batteries
- 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)

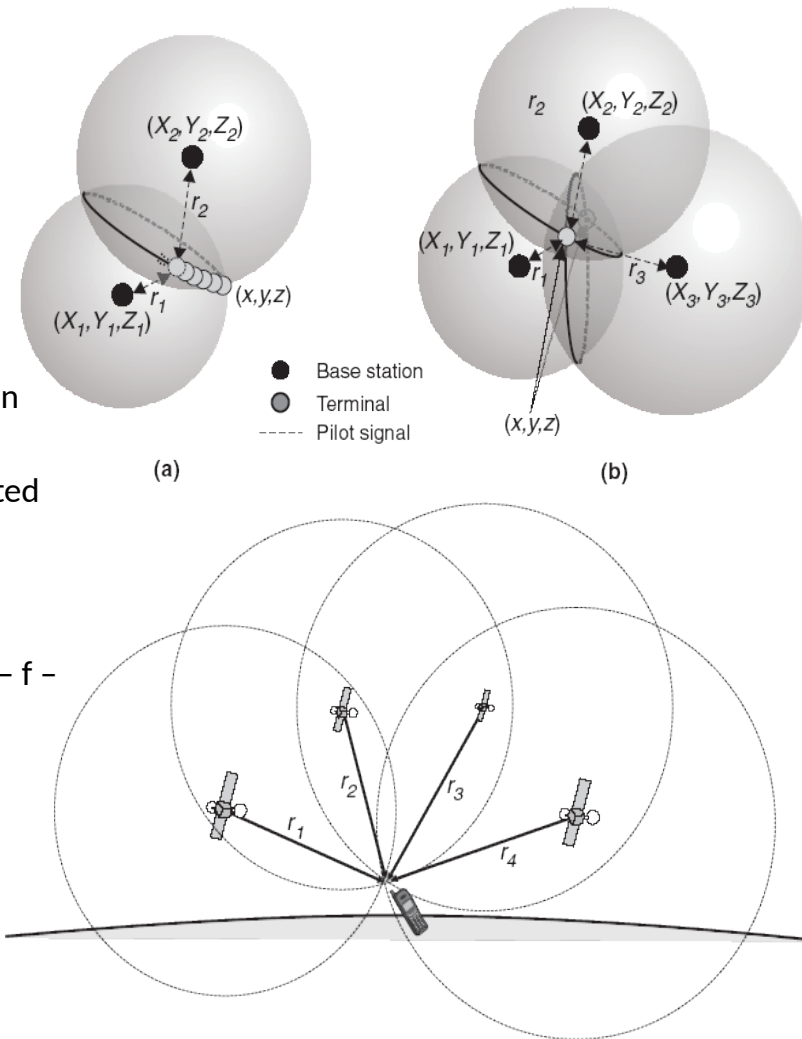
3.3 GPS – Components



- 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

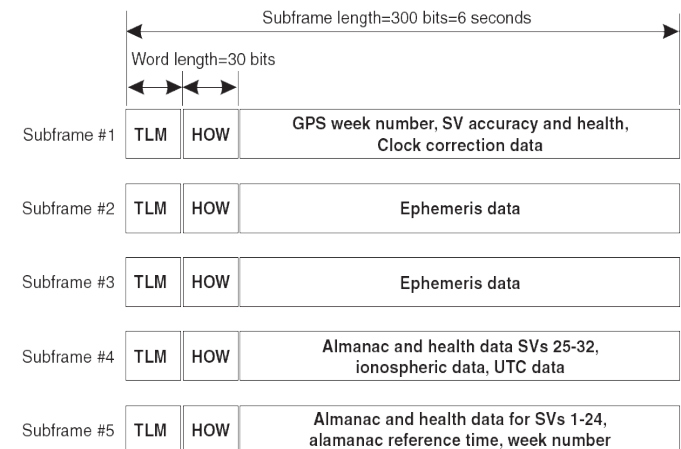
- **Known:**
 - Position $p_i = (x_i, y_i, z_i)$ for satellites $i \in \{1, 2, 3, 4\}$ at time t_i
 - Inaccurate reception time tr_i
 - Speed of light c
- **Unknown:**
 - Position p
- **Calculation:**
 - $r_i = (tr_i - t_i) * c$ for $i = 1, 2, 3$
 - Estimate position p_{est} : intersection of spheres (centered on satellite i with radius r_i)
 - Calculate distance r_4 and distance of satellite from estimated position
 - $d = |p_4 - p_{est}|$
 - Clock error of receiver: $f = (r_4 - d)/c$
 - Recalculation with corrected reception time $tr_i + f$: $r_i = (tr_i + f - t_i) * c$ for $i = 1, 2, 3$



3.6 GPS – Navigation Messages

- Transmitted at 50 bits per second
- Encoded with C/A and P-code and carries all data required for calculating position of the receiver
- Clock correction data
- Ephemeris
 - Position of the transmitting satellite (Keplerian elements)
 - Correction data (describing perturbing forces on the satellite)
 - ...
- Almanac
 - Subset of ephemeris data of all satellites
- Ionosphere data

TLM = Telemetry
word
HOW = Hand over
word



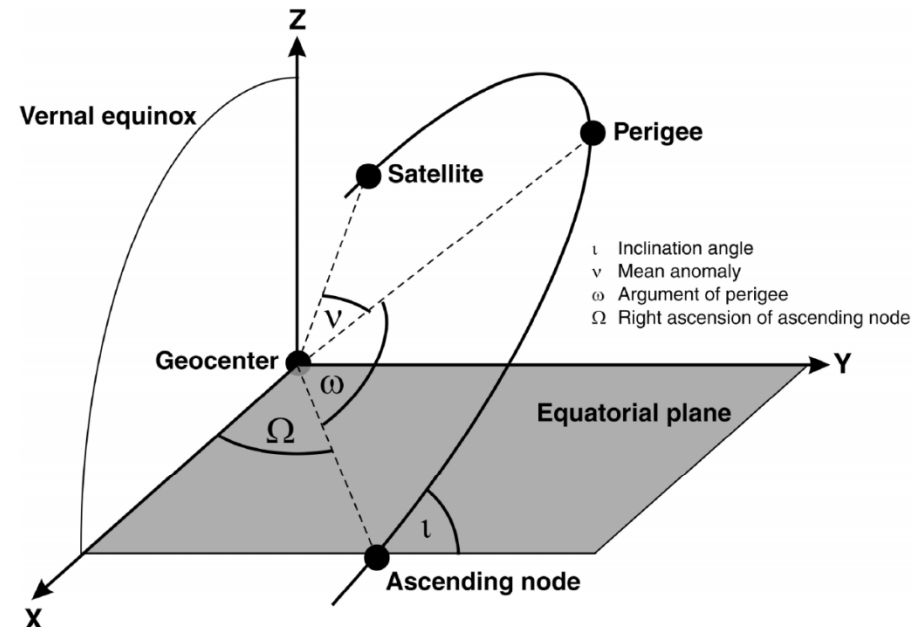
Almanac example for two satellites

***** Week 297 almanac for PRN-01 *****

ID:	01	Nummer des Satelliten
Health:	000	000 = Satellit funktionsfähig
Eccentricity:	0.5880832672E-002	Abweichung der Satellitenbahn von optimaler Kugelform
Time of Applicability(s):	589824.0000	Zeitpunkt der Almanach-Berechnung in Bezug auf die GPS Woche
Orbital Inclination(rad):	0.9840870249	Neigung der Satellitenbahn zum Äquator
Rate of Right Ascen(r/s):	-0.7428880871E-008	Änderung des Äquator-Schnittpunktes pro Sekunde
SQRT(A) (m 1/2):	5153.598633	Bahnradius (Wurzel aus der großen Halbachse)
Right Ascen at Week(rad):	-0.3119381016E+001	Schnittpunkt der Satellitenbahn am Äquator zum Wochenbeginn
Argument of Perigee(rad):	-1.660391890	Winkel, in welchem der Satellit den größten Abstand zur Erde hat
Mean Anom(rad):	0.9436667061E+000	Aktuelle Position des Satelliten auf seiner Bahn
Af0(s):	0.4024505615E-003	Abweichung der Satelliten-Zeit von der GPS-Systemzeit (hier 0,4 ms)
Af1(s/s):	0.3637978807E-011	Messfehler der Atomuhr des Satelliten (hier 3,6 Picosekunden zu viel)
week:	297	die 297ste GPS-Woche seit dem 22. August 1999 (hier 1. Mai 2005)

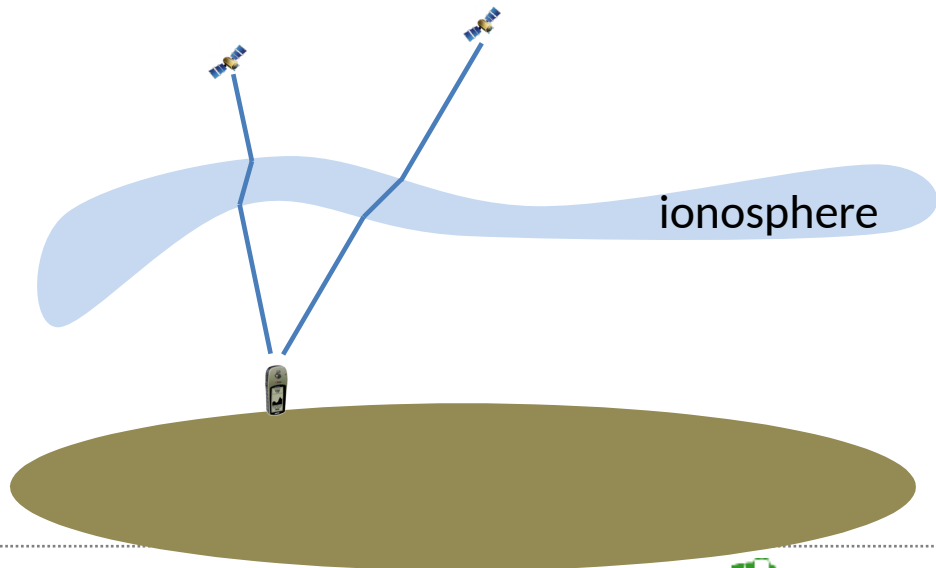
***** Week 297 almanac for PRN-02 *****

ID:	02
Health:	000
Eccentricity:	0.9529113770E-002
Time of Applicability(s):	589824.0000
Orbital Inclination(rad):	0.9551331376
Rate of Right Ascen(r/s):	-0.8183198006E-008
SQRT(A) (m 1/2):	5153.635742
Right Ascen at Week(rad):	0.1038484770E+001
Argument of Perigee(rad):	1.827911506
Mean Anom(rad):	0.2496773193E+001
Af0(s):	-0.2574920654E-004
Af1(s/s):	0.0000000000E+000
week:	297



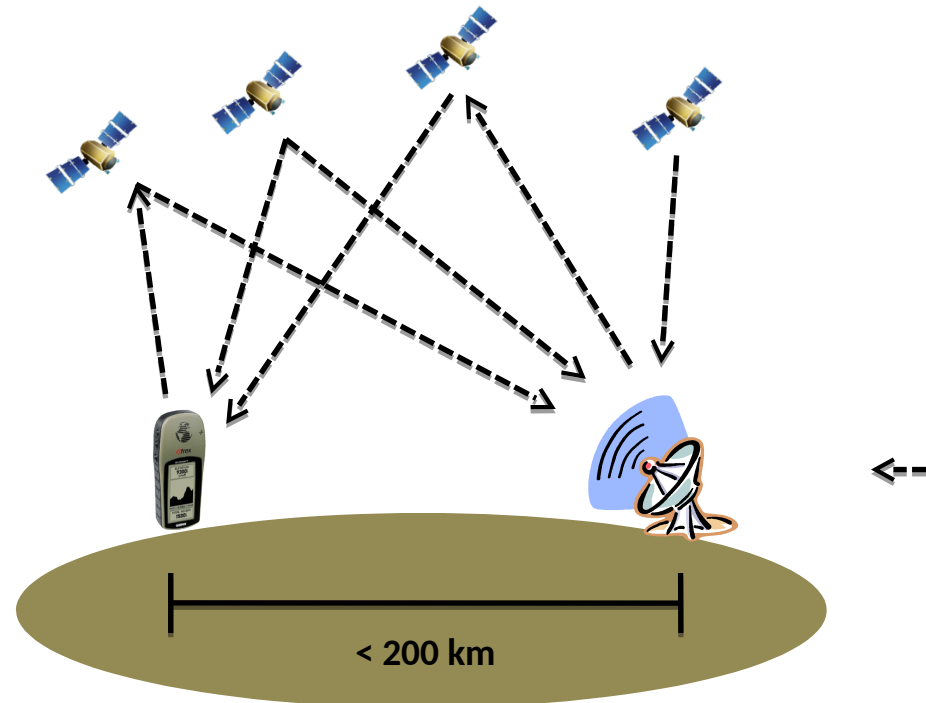
3.7 GPS - Possible Errors

- 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

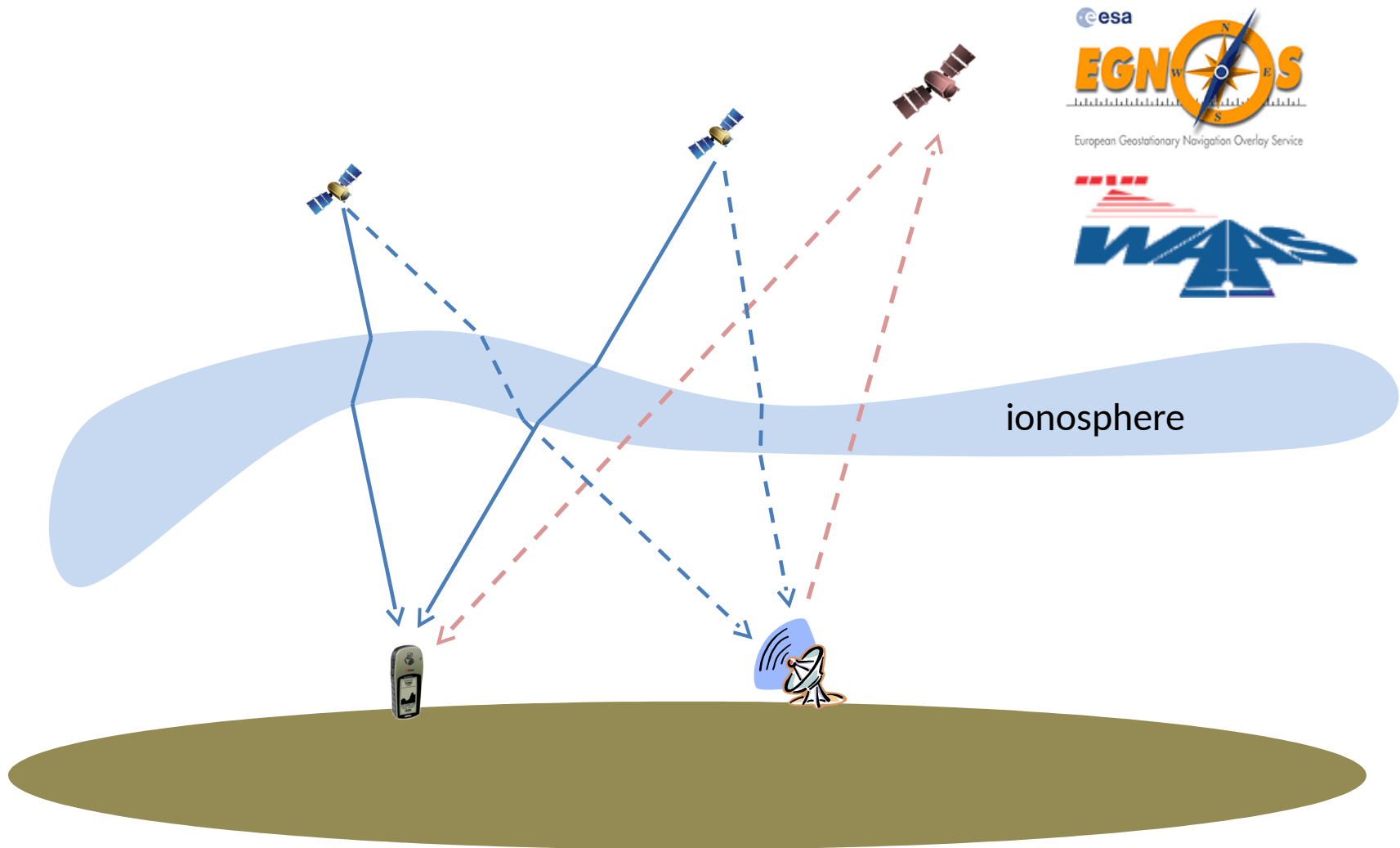


3.8 Differential GPS (DGPS)

- 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



3.9 Satellite-based Augmentation Systems



3.10 National Marine Electronics Association NMEA

- International standard for data exchange
- Used in most GNSS receivers for data interface
- Specifies data sets for various applications
- (GGA, GGL, GSA, GSV, RMC, VTG, ZDA)
- Transmitted with 4800 Baud using printable 8-bit ASCII

Field	Description
\$	Start of the data set
GP	GNSS appliance
DS-ID	Data set identifier
F_1 to F_n	Information 1 ... n
,	Comma used as separator
*	Asterisk used as separator for checksum
CS	Checksum for entire data set

`$GPRMC,133040.0,A,4811.332,N,011384.332,E,001.00,230.0,220609,01.3,W*CS`

3.10 NMEA - example

Example: RMC = Recommended Minimum Specific GNSS

\$GPRMC,130304.0,A,4717.115,N,00833.912,E,000.04,205.5,200601,01.3,W*7C<CR><LF>

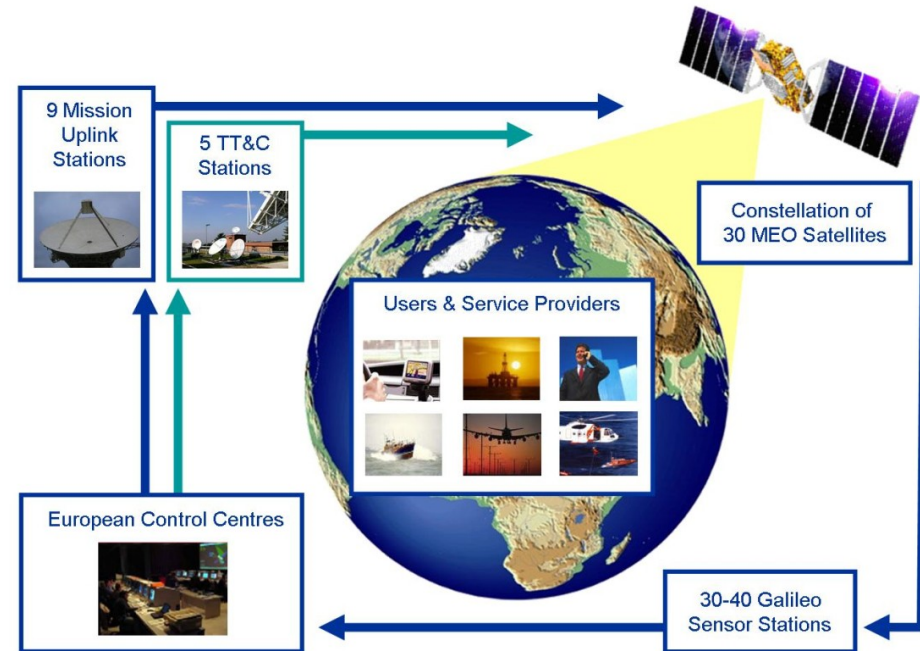
Field	Description
\$	Start of the data set
GP	Information originating from a GNSS appliance
RMC	Data set identifier
130304.0	Time of reception (world time UTC): 13h 03 min 04.0 sec
A	Data set quality: A signifies valid (V= invalid)
4717.115	Latitude: 47° 17.115 min
N	Northerly latitude (N=north, S= south)
00833.912	Longitude: 8° 33.912 min
E	Easterly longitude (E=east, W=west)
000.04	Speed: 0.04 knots
205.5	Course: 205.5°
200601	Date: 20th June 2001
01.3	Adjusted declination: 1.3°
W	Westerly direction of declination (E = east)
*	Separator for the checksum
7C	Checksum for verifying the entire data set
<CR><LF>	End of the data set

4. Galileo

- European GNSS
- 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 will lead to higher precision
 - Availability/Coverage : 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.

4.2 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

4.3 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 e.g. aviation.
- 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;
- 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

5. Other GNSS

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

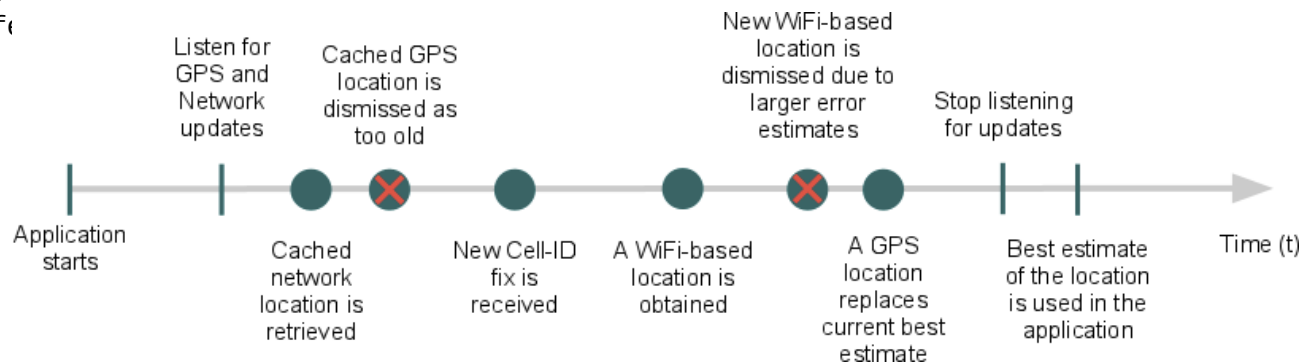
```
// Acquire a reference to the system Location Manager
LocationManager locationManager = (LocationManager)
this.getSystemService(Context.LOCATION_SERVICE);

// Define a listener that responds to location updates
LocationListener locationManager = new LocationListener() {
    public void onLocationChanged(Location location) {
        // Called when a new location is found by the network location provider.
        makeUseOfNewLocation(location);
    }

    public void onStatusChanged(String provider, int status, Bundle extras) {}
};

// Register the listener with the Location Manager to receive location updates
locationManager.requestLocationUpdates(LocationManager.GPS_PROVIDER, 0, 0, locationManager);
```

```
<manifest ... >
    <uses-permission android:name="android.permission.ACCESS_FINE_LOCATION" />
    ...
</manifest>
```



<https://developer.android.com/guide/topics/location/strategies.html>

Stromsparmaßnahmen:

“GPS, Cell-ID, and Wi-Fi can each provide a clue to users location. Determining which to use and trust is a matter of trade-offs in accuracy, speed, and battery-efficiency.”

- Zeitspanne reduzieren, in der auf Positionierungsdienst zurückgegriffen wird
- Frequenz reduzieren, in der Positionierungsdaten geliefert werden
- Menge der Location-Provider reduzieren (nur NETWORK / nur GPS)
-

Zum Testen: “Falsche” Position einstellen:

- telnet localhost <console-port>
- geo fix -121.45356 46.51119 4392
- oder:
 - geo nmea
\$GPRMC,081836,A,3751.65,S,14507.36,E,000.0,
360.0,130998,011.3,E*62