LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Praktikum Mobile und Verteilte Systeme

Outdoor Positioning Systems

Prof. Dr. Claudia Linnhoff-Popien
Philipp Marcus, Mirco Schönfeld
http://www.mobile.ifi.lmu.de

Sommersemester 2015

Outdoor Positioning Systems - Introduction

Today:

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

Next week:

- Indoor Positioning Systems

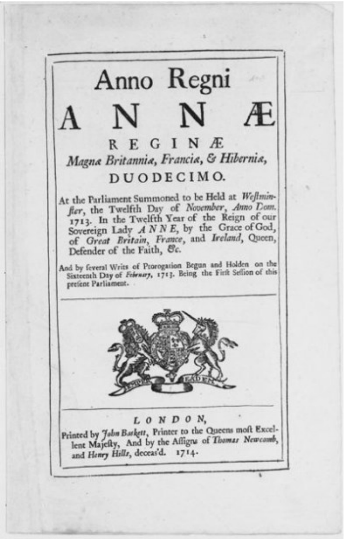
1. History of Positioning I

- 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.



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.

- Expected accuracy (drift):
  - Maximum error: 0,5 degrees
  - 0,5 degrees = 30 nautical miles at the equator

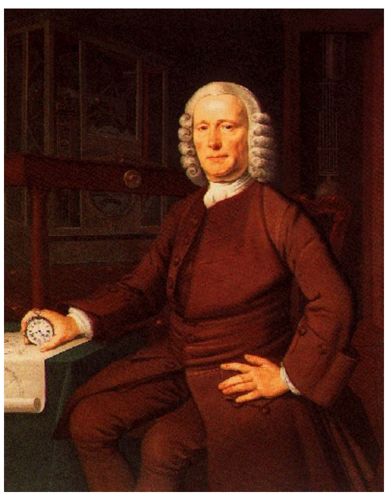
    = motion during 2 minutes of earth rotation

    = 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

H2

H3

H4

13cm

1.45 kg

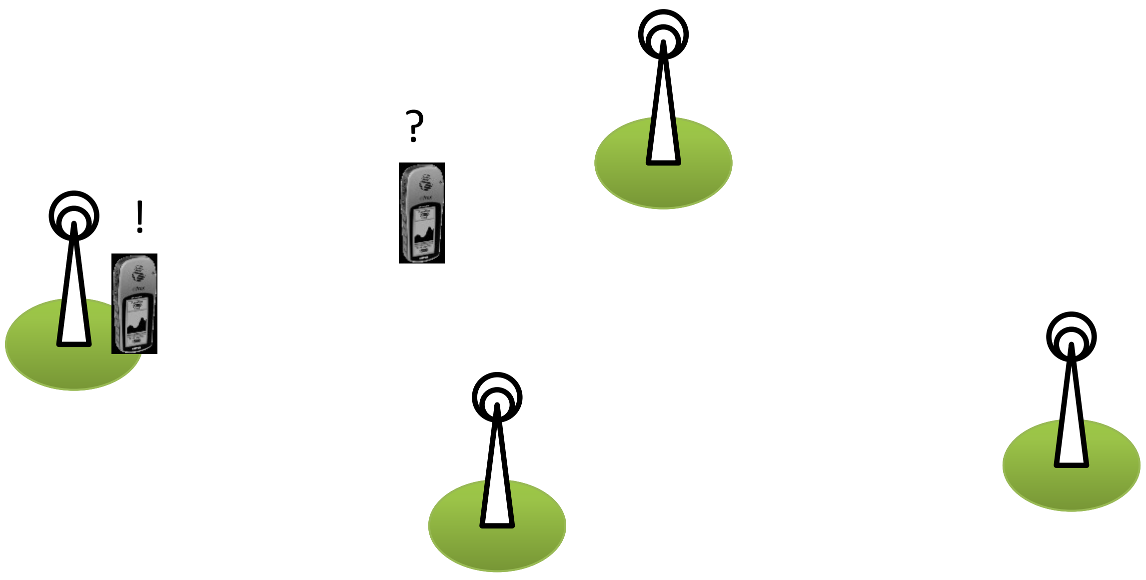
2. Positioning Fundamentals – Components

- 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	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

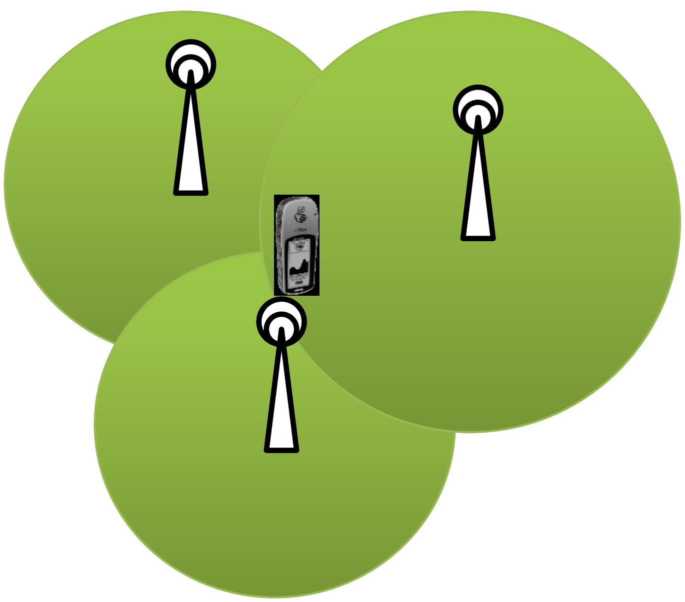
Proximity Sensing

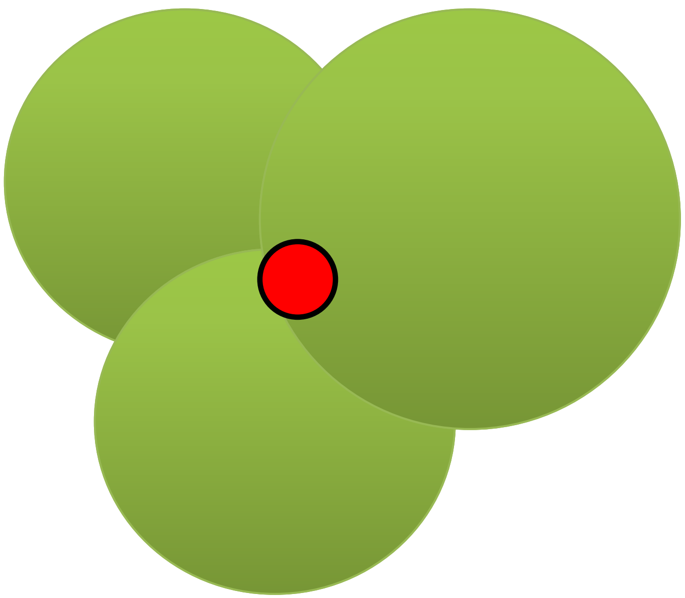
- Proximity is sensed by a station using (short) range pilot signals:



Lateration

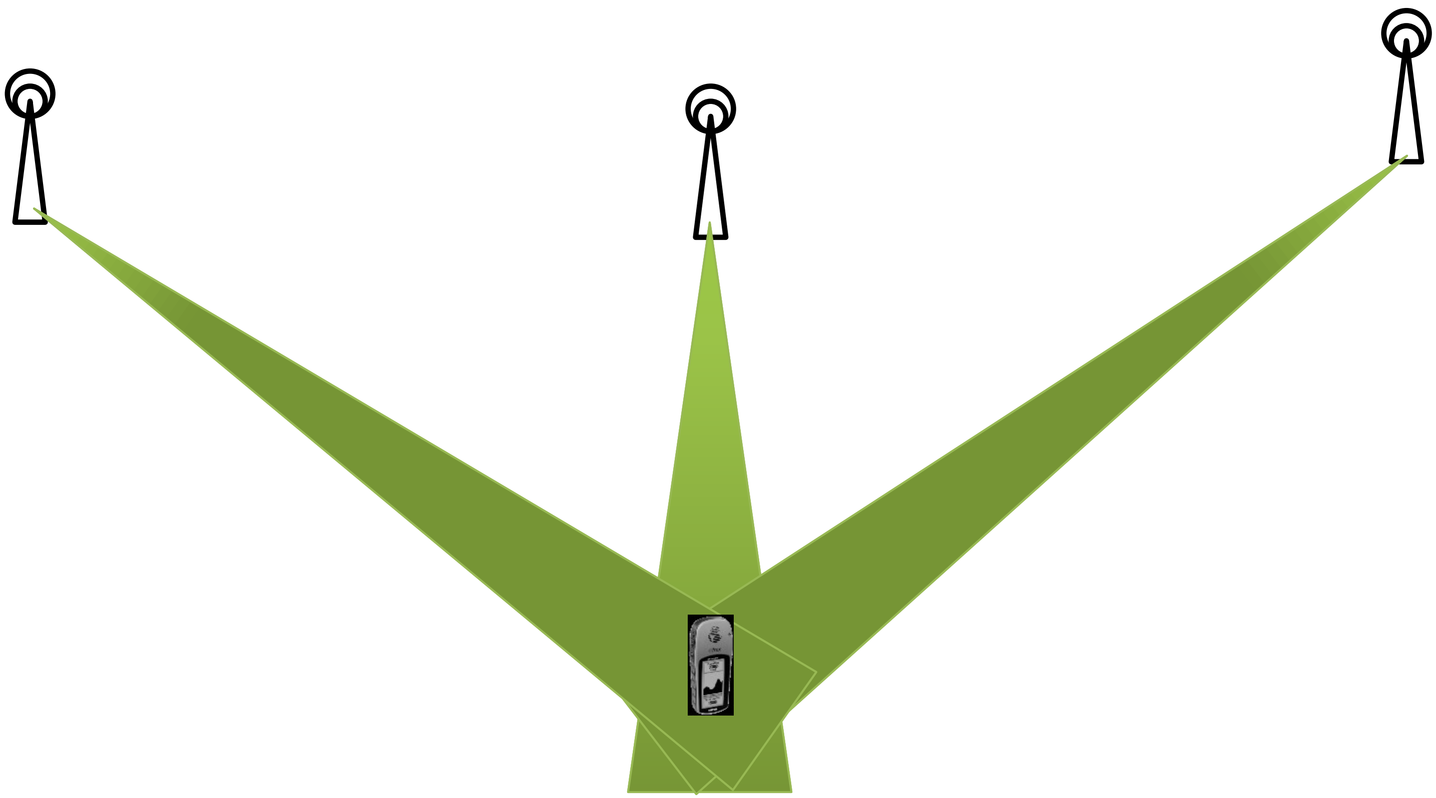
- Position is computed by a number of range measurements to known fix-points:





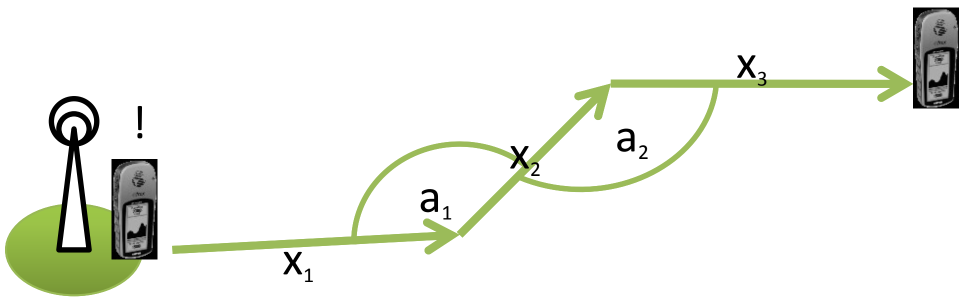
Angulation

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



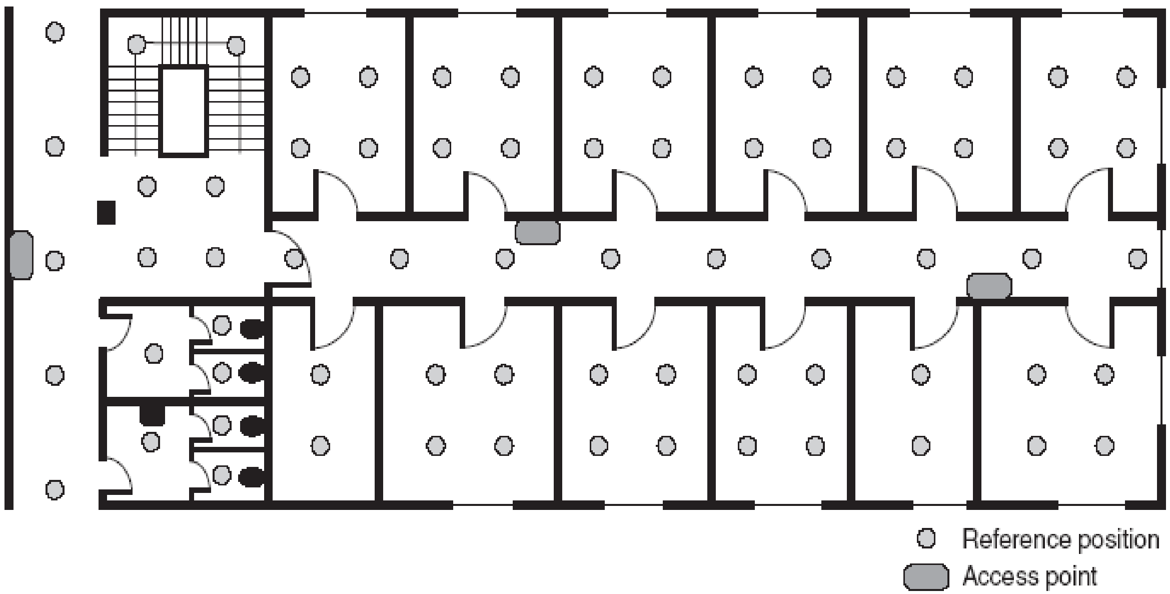
Dead Reckoning

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



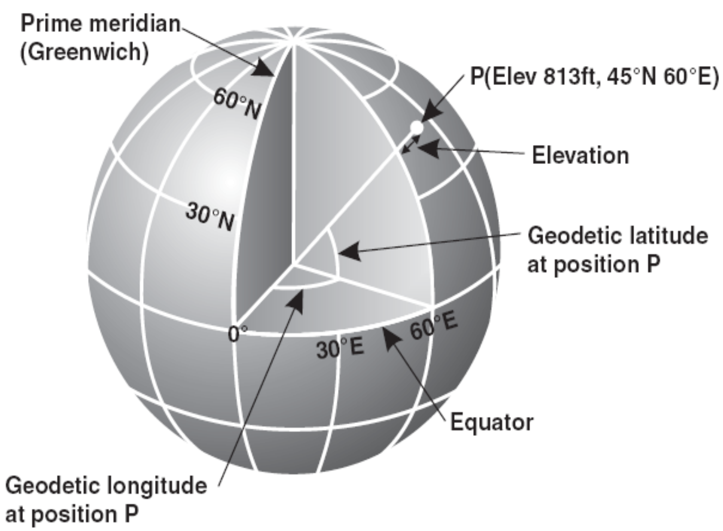
Fingerprinting

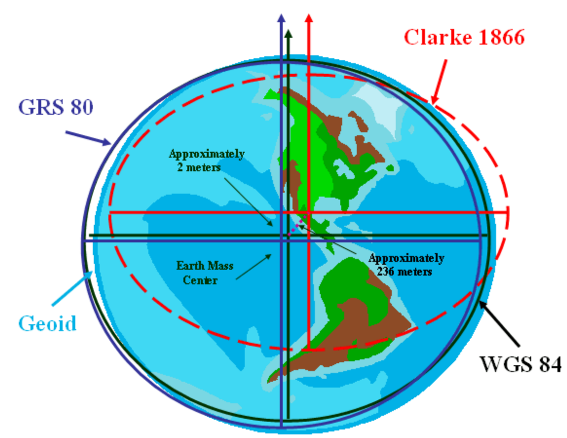
- Position is derived by the comparison of location dependent online measurements with previously recorded data:



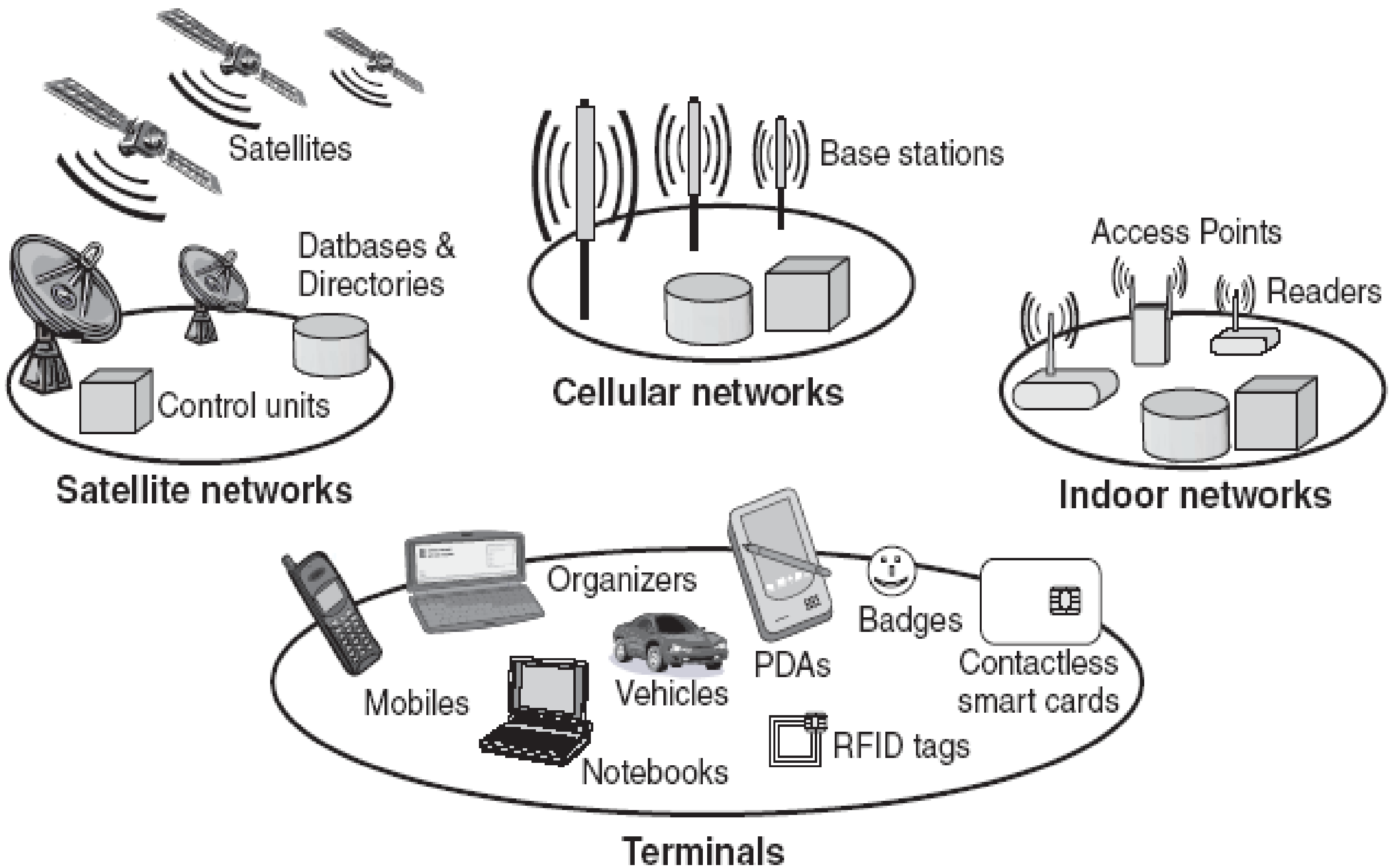
2.1 Positioning Fundamentals – Reference Systems

- 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

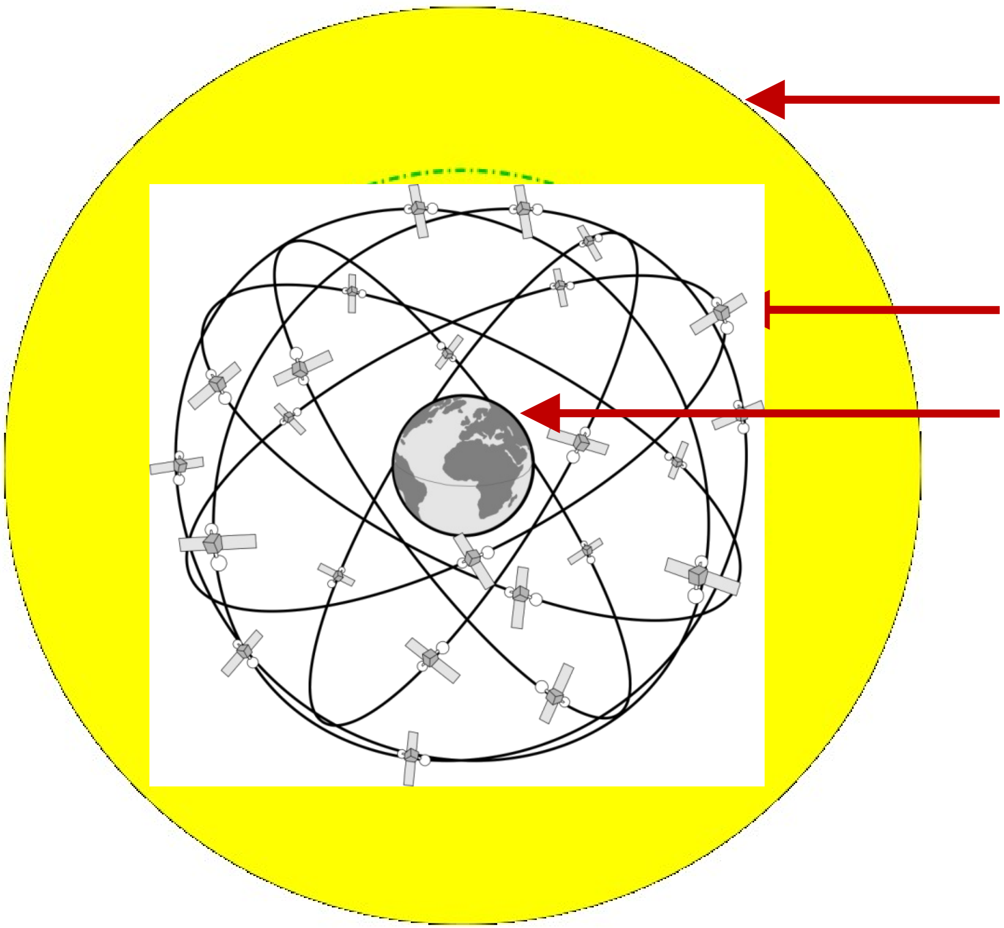
3. GPS – Mission Goals

- 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 $ 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)

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)

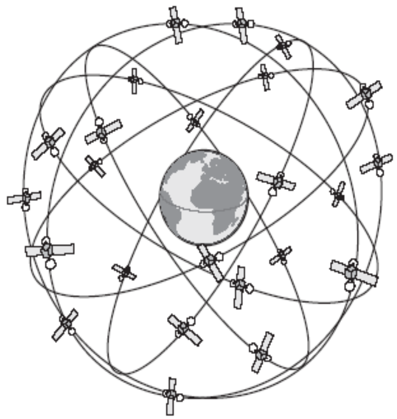
GPS satellites (ca. 20.200 km)

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



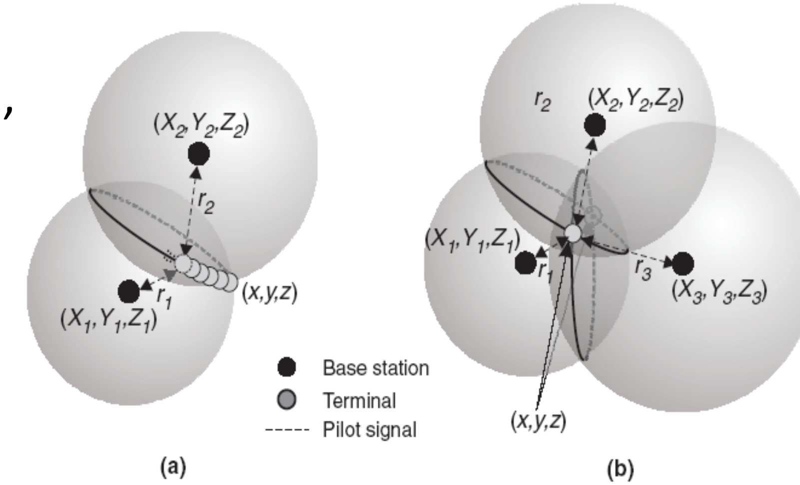
- Space segment
  - 24 satellites circulating the Earth every 12 sidereal hours on six orbits
  - Each satellite is equipped with onboard atomic clocks
  - Orbits are equally spaced 60° apart from each other with an inclination angle of 55° to the equator
  - Orbit altitude: approx. 20,180 km

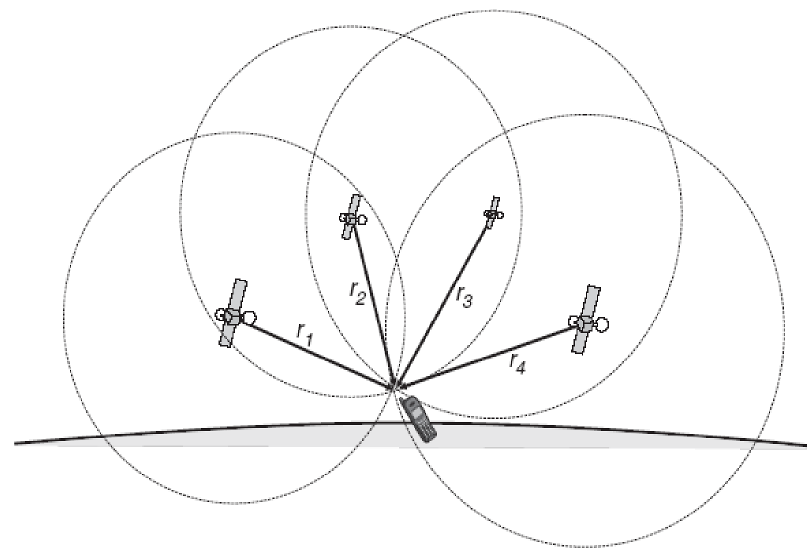
- Control segment
  - Initially: Five ground stations for monitoring and controlling the satellites
  - In 2005: Six additional monitoring stations
  - Adjust or synchronize satellites

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

3.4 GPS – Circular Lateration

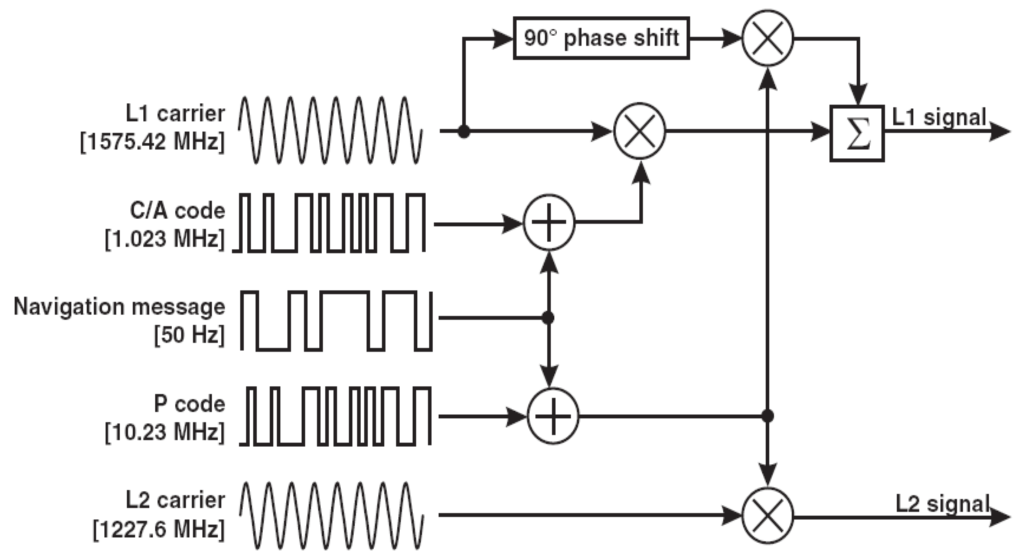
- **Known:**
  - Position $p_i = (x_i, y_i, z_i)$ for satellites i ϵ {1, 3, 4} at time t_i
  - Inaccurate reception time tr_i
  - Speed of light c
- **Unknown:**
  - Position p
- **Calculation:**
  - $r_i = (tr_i – t_i)*c$ for i = 1,2,3
  - Estimate position p_{est} : intersection of spheres (centered on satellite i with ra $r_{i)}$
  - 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 receptio time $tr_i + f$: $r_i = (tr_i – f – t_i)*c$ for i = 1,2





3.5 GPS – Signals

- Modulation scheme: QPSK
- Multiple Access: CDMA (i.e., all satellites use the same carrier frequencies)
- L1: 1575.42 MHz
  - Carries the Coarse Acquisition (C/A) Code for civil application
  - Carries the Precise (P) Code for military applications
- L2: 1227.6 MHz
  - Carries the Precise (P) Code for military applications
- Future extensions:
  - L5 for improved civil services
  - M-code for military applications

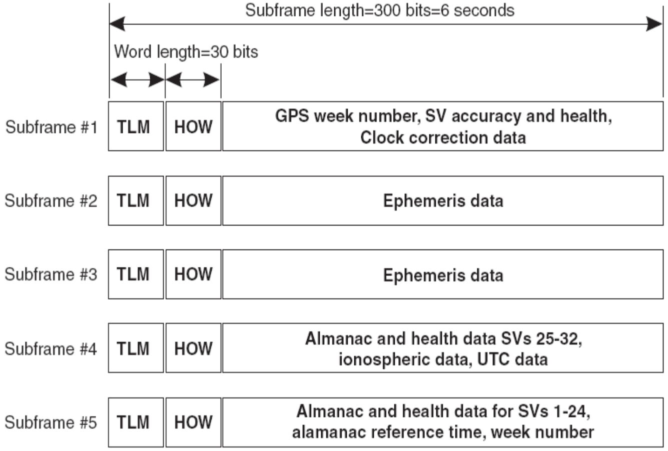


3.6 GPS – Navigation Messages

- 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



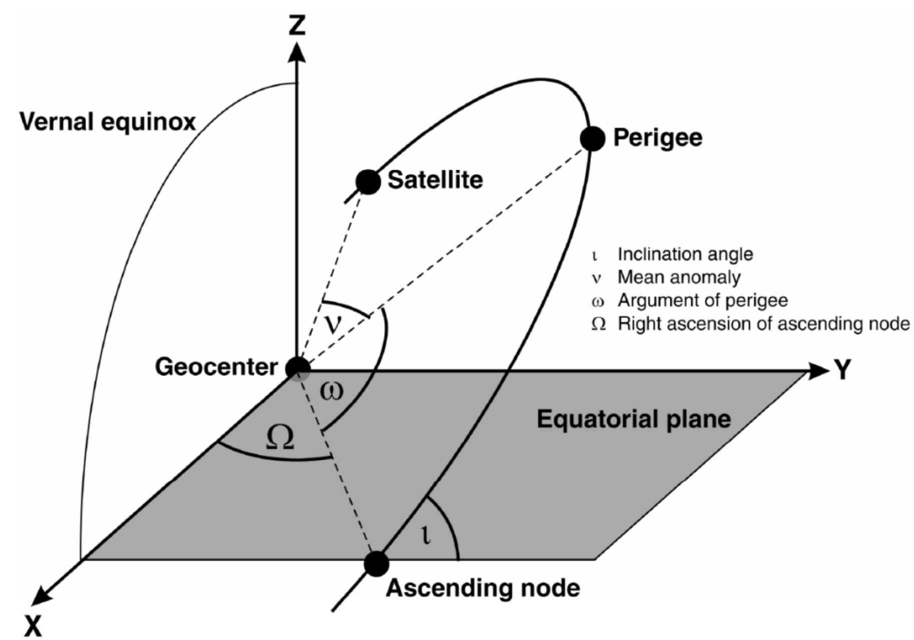
Almanac example for two satellites

******** 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	<u>Zeitpunkt der Almanach-Berechnung</u> 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 <u>Position des Satelliten</u> 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)

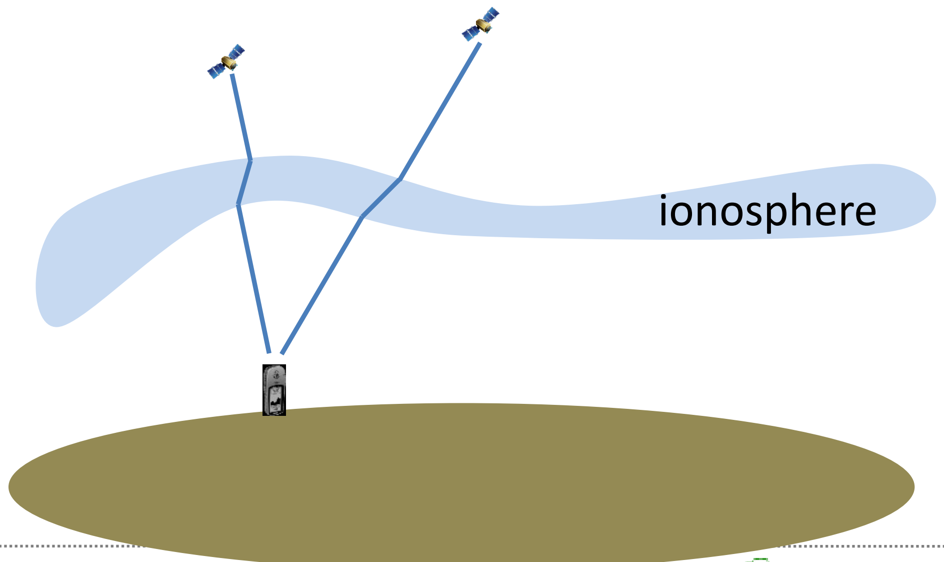
******** Week 297 almanac for PRN-02 ********

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



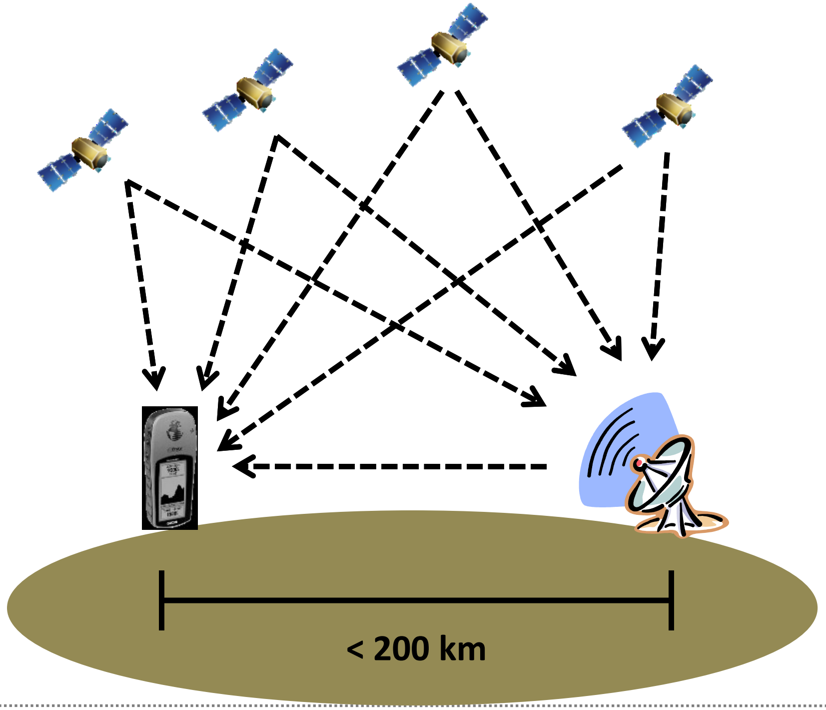
3.7 GPS - Possible Errors

- 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

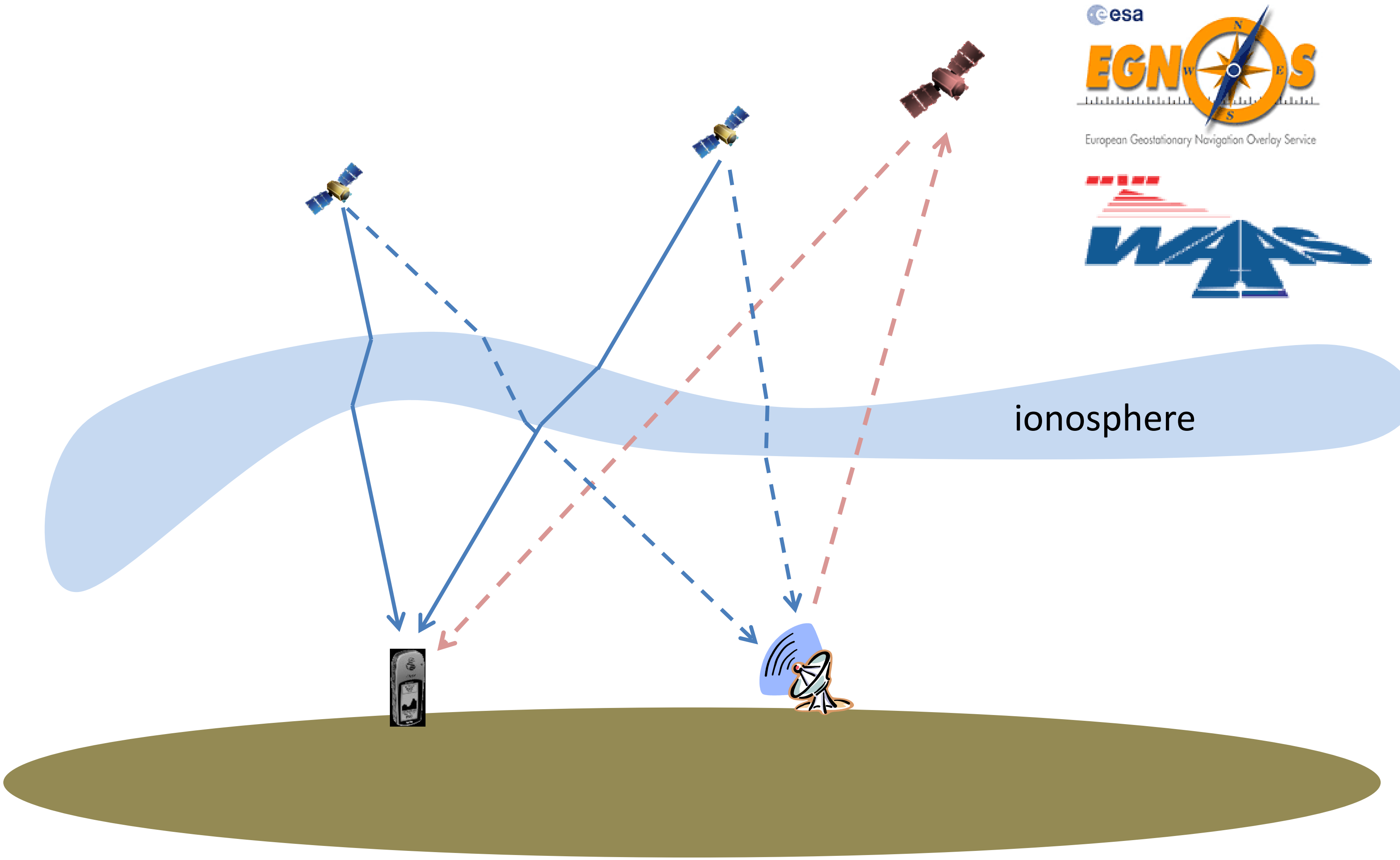


3.8 Differential GPS (DGPS)

- 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

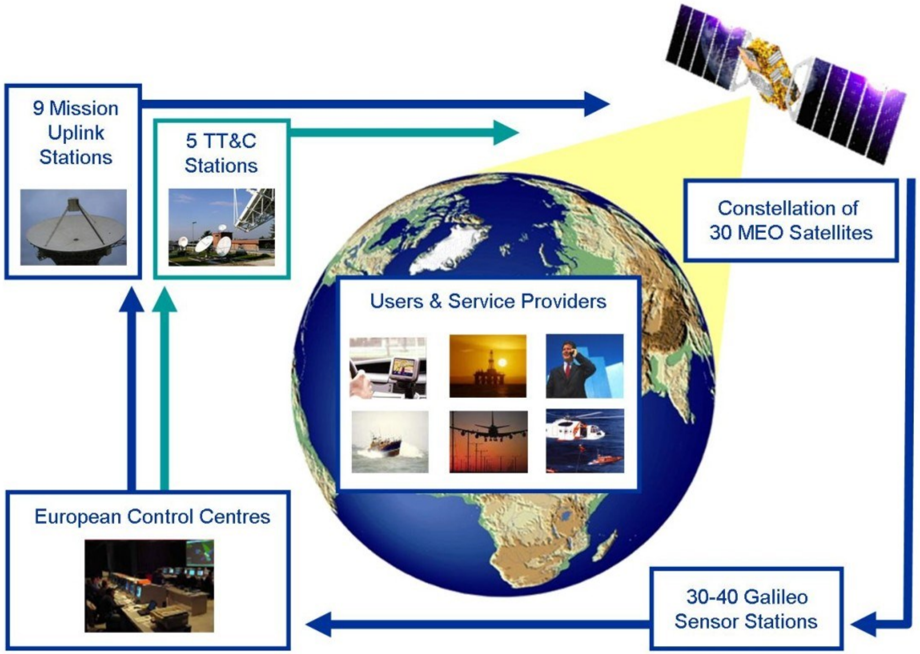
- European GNSS
- Independence of other systems
- More services: Open, Commercial, Safety of Life, Public Regulated, Search and Rescue
- Advantages
  - Precision: Combination of GPS and Galileo in dual receivers will lead to higher precision
  - Availability/Coverage : Higher number of satellites will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

4.1 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

4.2 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)

Outdoor Positioning Systems - Practical

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