LECTURE

5

Global navigation satellite systems (GNSS) - European Galileo system

Zuzana Bělinová
Faculty of Transportation Sciences, Czech Technical University in Prague

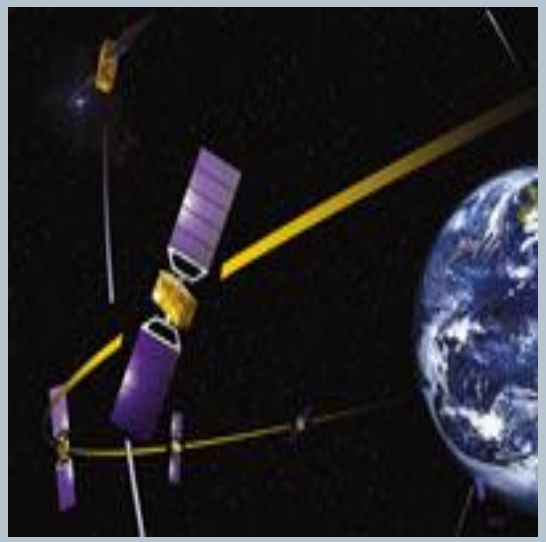
Lecture 5 – Overview

- Galileo GNSS
  - Development
  - Architecture
  - Principle
  - EGNOS
- GNSS applications

GALILEO system

GALILEO system

- first independent satellite system
  (GPS and GLONASS are military controlled)
- European project
- actual expected price app. 7 billions €



Zdroj: www.czechspace.cz

Galileo plans and visions

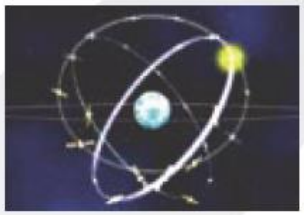
- Benefit for Cost Ratio was estimated to be 4.6
  (e.g. traffic infrastructure project typically have 1,5 - 2)
- System should create 140 000 working positions in Europe
- Significant impacts due to starting telematic applications using Galileo
- Galileo system history
  - 1999 – joint plans of several European countries
  - 2001-2005 (definitions, satellite development, etc..)
  - financing problems, 2007 EU financing approved instead of partnership with industry
  - In full operation maybe from 2020

Galileo implementation plan

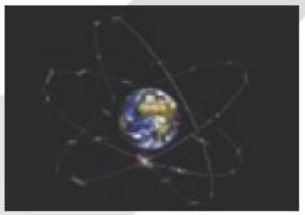
Galileo implementation plan

Galileo System Testbed
GIOVE A, GIOVE B, GIOVE mission segment

In-Orbit Validation
4 IOV satellites and ground segment



FOC Phase 1
Open Service, Search & Rescue,
Public Regulated Service
Total 18 satellites and ground segment



FOC Phase 2
All services
Total 30 satellites and ground segment

Source: http://download.esa.int/docs/Galileo_IOV_Launch/BR-297_Galileo_web.pdf

Galileo system development

- System development is ensured by companies from Italy, Germany and France based on a selection procedure (assigned by European Commission 8.1.2010)
  - Development of first 4 satellites is carried out by EADS Astrium (previous contract), newly next 22 satellites developed by German company OHB Systems AG
  - Launch is ensured by French Arianespace
  - Global system support is ensured by Italien ThalesAleniaSpace

Galileo satellite test beds

- GIOVE (Galileo In-Orbit Validation Element)
  - GIOVE-A launched on 28 December 2005 by the European Space Agency and the Galileo Joint. Operation
    - ensured that Galileo meets the frequency-filing allocation and reservation requirements for the International Telecommunication Union (ITU), a process that was required to be complete by June 2006.
  - GIOVE-B launched on 27 April 2008 aboard a Soyuz-FG/Fregat rocket provided by Starsem.

Galileo in present and in the future

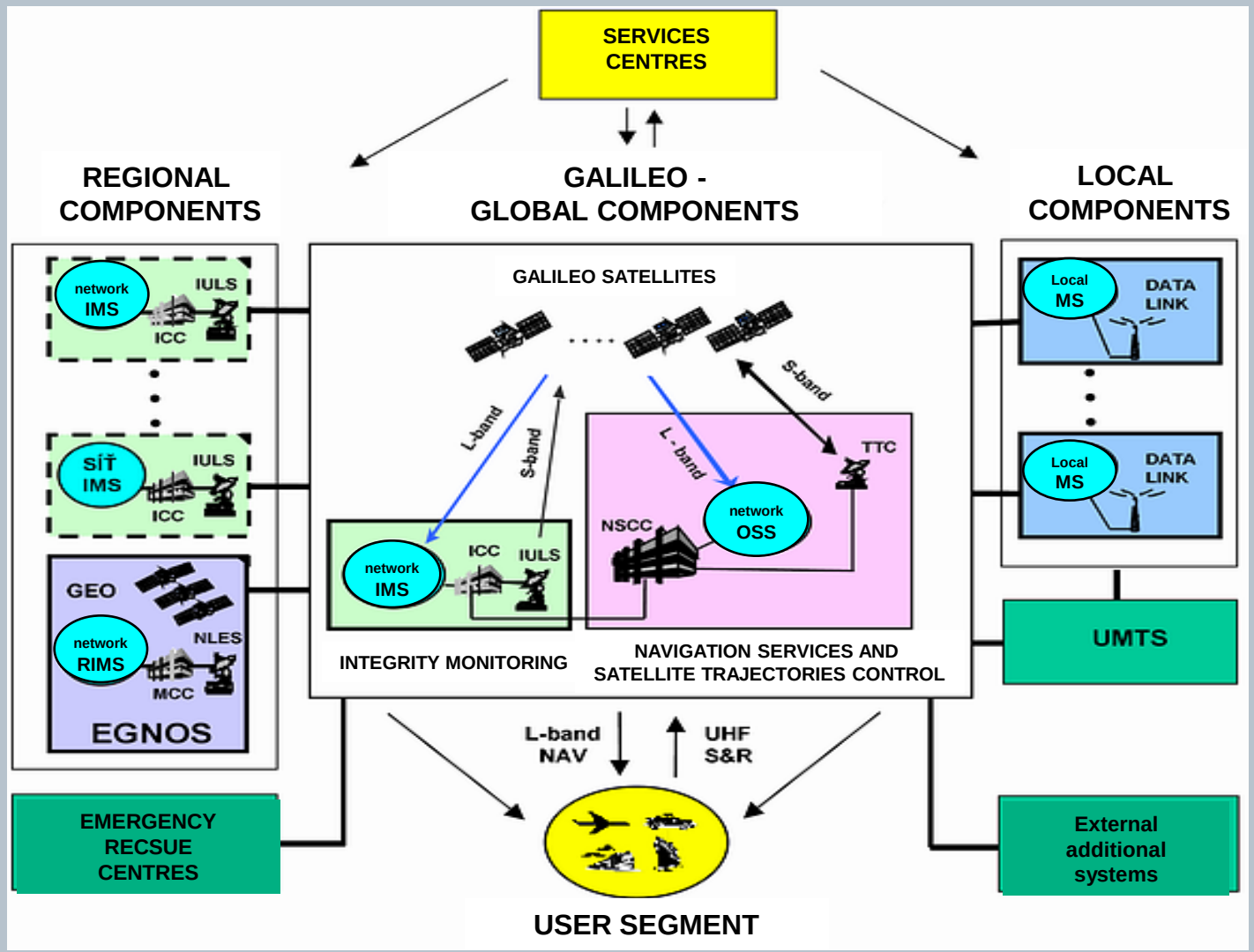
- Launches
  - In-orbit validation satellites
    - 21.10.2011 Sojuz rocket launched from Kourou cosmodrome placed first two satellites into orbit
    - 12.10.2012 two more satellites launched from Kourou
      →2013 in-orbit-validation phase finished
  - Full operational capability satellites launched from 2014
    - Now 6 satellites in orbit
    - Last pair of satellites launched 11.9.2015
    - Next launch expected in December 2015

- Future
  - By mid-decade 18 satellites in orbit providing initial services
  - Expected full operational capability in ca 2020 – worldwide coverage, all satellites

Galileo supervision

- European GNSS Agency
  (formerly GSA – GNSS Supervisory Authority 2004-2014, GALILEO Joint Undertaking 2002-2007)
- Agency of the European union
- Two parts – administrative and security one
- The Czech Republic is the seat of the administrative centre - in Prague (confirmed 10.12.2010, moved during September 2012)
- Security and monitoring centre will be in France and Britain

Galileo system components



GALILEO

- Fully deployed Galileo system consists of 30 satellites (27 operational + 3 active spares),
- Positioned in 3 circular Medium Earth Orbit (MEO) at 23 222 km with orbit period 14 hours 4 minutes
- Inclination 56° to the equator level
- Good coverage even at latitudes up to 75 degrees north
- Planned several types of services
  - open on frequencies 1164-1214 MHz and 1563-1591 MHz, accuracy ca 10 m
  - encrypted Commercial Service using frequency 1260-1300 MHz, accuracy ca 1 m
  - encrypted for security authorities (police, military, etc.) and safety-critical transport applications – improved jam resistance, higher reliability

Galileo subsystems – cosmic sector

- Cosmic sector:
  - 27+3 spare satellites
  - Satellite payload
    - 2 Passive Hydrogen Maser atomic clocks;
    - 2 Rubidium atomic clocks;
    - Clock monitoring and control unit;
    - Navigation signal generator unit;
    - L-band (1-2 GHz) antenna for navigation signal transmission,
    - C-band (4-8 GHz) antenna for uplink signal detection,
    - 2 S-band (2-4 GHz) antennas for telemetry and telecommands;
    - Search and rescue antenna

Galileo rubidium clock

Galileo subsystems – ground sector

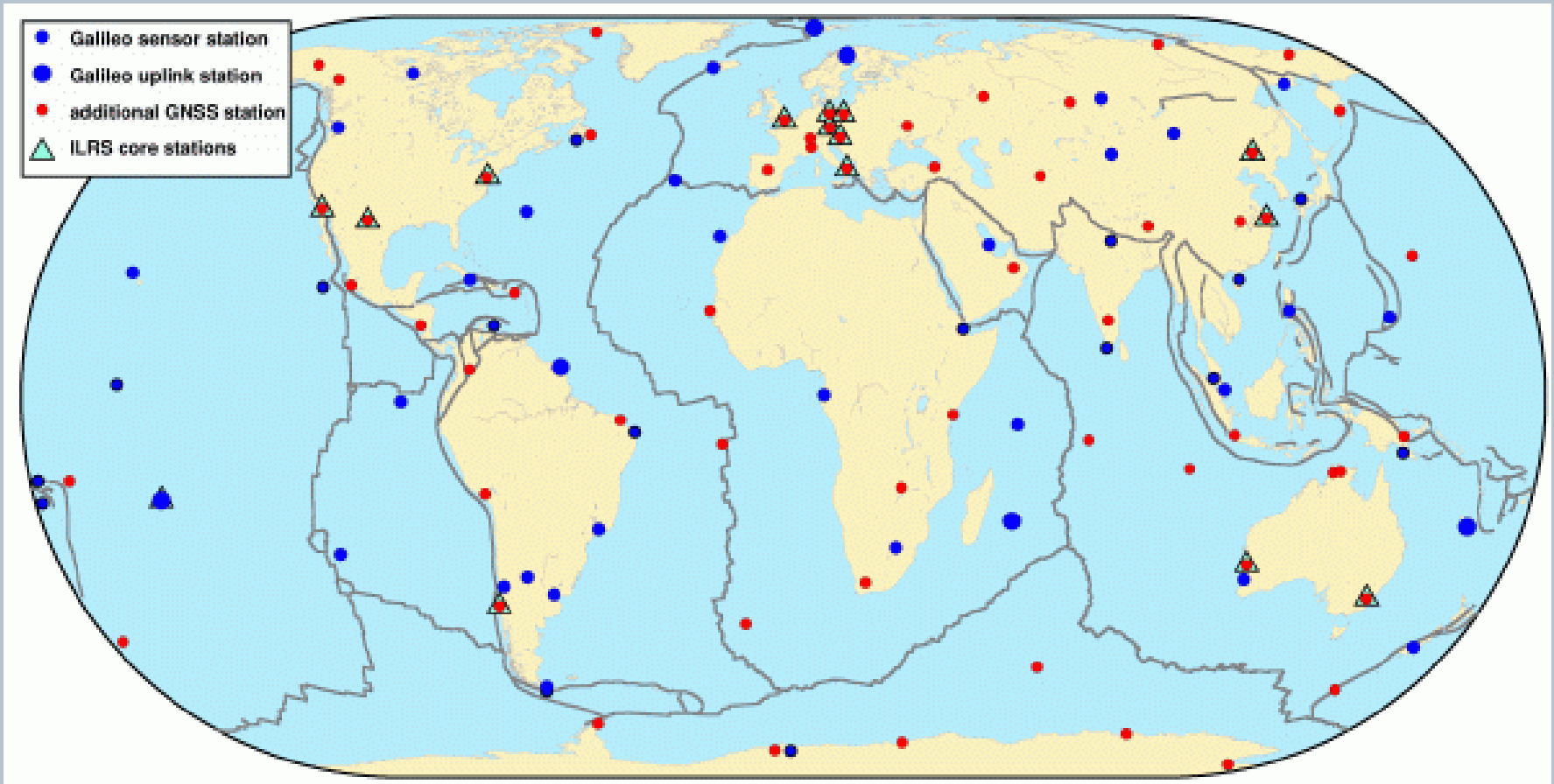
- Ground sector: Galileo Control Centres (GCCs) for the control of the satellites, to perform the navigation mission management, control of service integrity, etc.:
  - **Ground Control Segment, GSC**
    - Functions:
      - Telemetry acquisition and Telecommand uplink,
      - control and monitoring of the satellites and payload,
      - satellite ranging,
      - constellation monitoring and control;
      - planning and automation functions that allow safe and correct operations to take place
      - support of payload related operations such as uplink of navigation data – control and check functions, satellite position maintenance, etc.
    - Oberpfaffenhofen Control Centre in Germany
  - **Ground Mission Segment, GMS**
    - Functions:
      - functions necessary to acquire and process the navigation data,
      - to determine the navigation, timing and integrity data part of the navigation messages and to transmit it to the satellite.
      - Search & Rescue service
    - Fucino Control Centre in Italy

Galileo subsystems – ground sector

- Other components
  - TT&C Tracking, Telemetry and Command stations
    - Kiruna in Sweden
    - Kourou in French Guiana
  - Galileo Sensor Stations, GSS
    - global network (30 stations)
    - provide coverage for clock synchronisation and orbit measurements
  - Uplink Stations
    - to uplink the navigation and integrity data
  - Data Dissemination Network
    - interconnecting all Galileo ground facilities
  - etc.

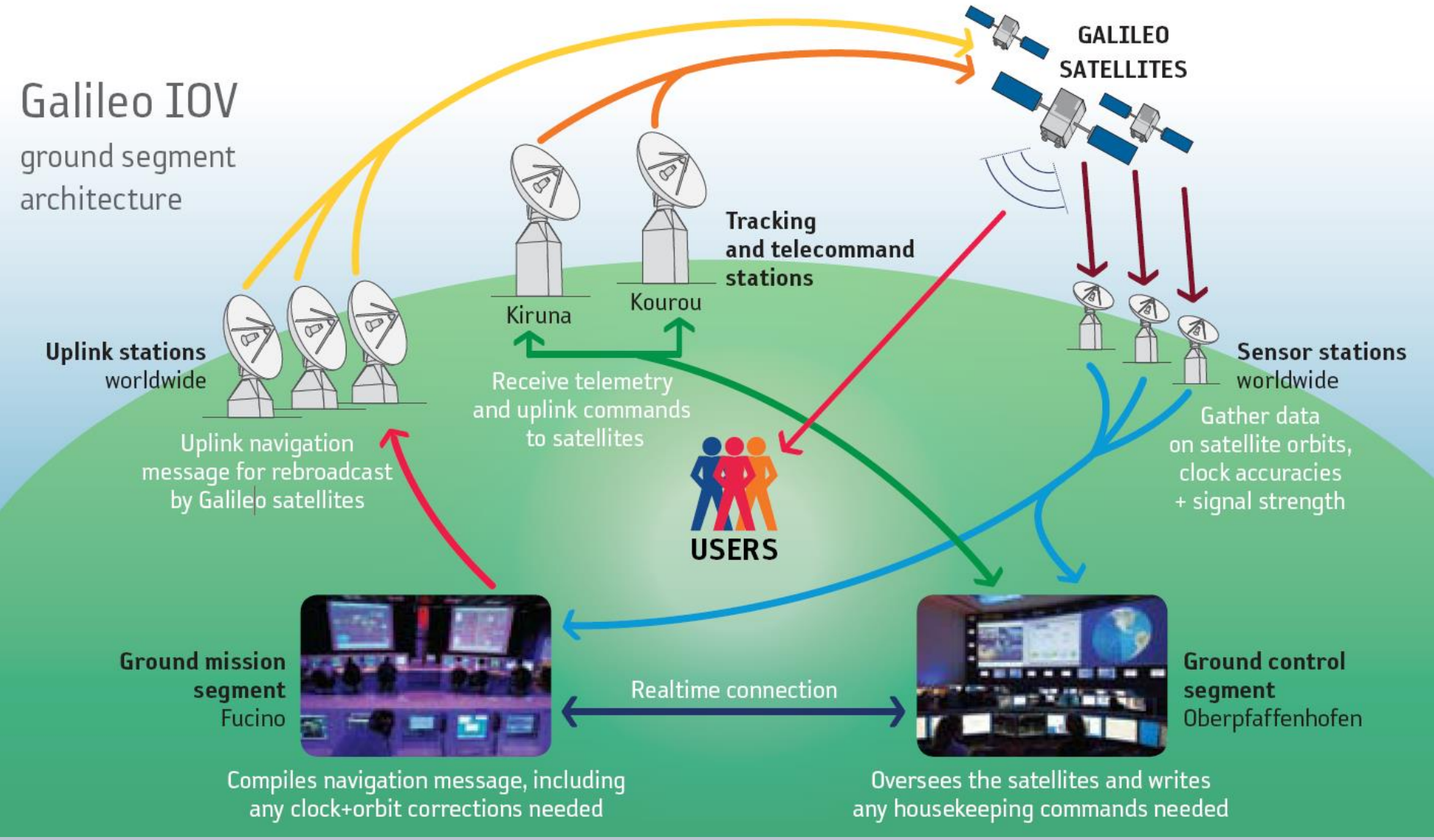
Galileo subsystems – ground sector

- Galileo stations – blue points



Source: http://www.ggsp.eu/ggsp_gtrf.html

Galileo in-orbit-validation architecture



Source: http://download.esa.int/docs/Galileo_IOV_Launch/BR-297_Galileo_web.pdf

How it works – time and position corrections - time

- GST – Galileo System Time
  - Accurate to 28 billionths of a second
  - generated by the Precise Timing Facilities at the Galileo Control Centres:
    - in Fucino, Italy
    - Oberpfaffenhofen, Germany,
  - cross-checked for alignment to the International Coordinated Universal Time by a group of European timing laboratories
- ground stations continuously checks each satellite's clock

How it works – time and position corrections - position

- Ground stations pick satellite signals
- Pinpoint satellite positions

- correcting message are sent uplink to the satellites
- rebroadcast to users in the satellite signals themselves

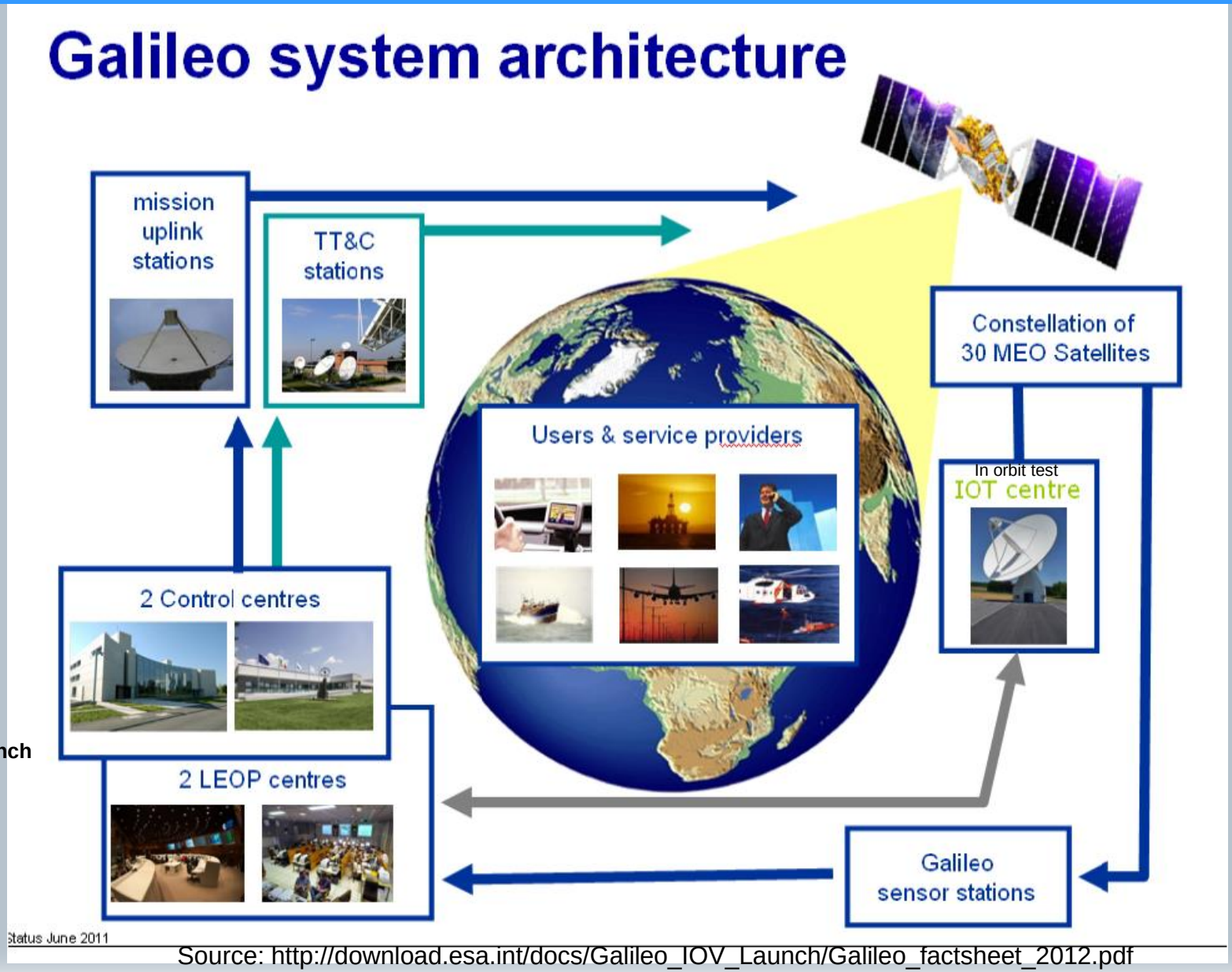
Galileo antenna
Kiruna, Sweden

Source: http://www.esa.int/Our_Activities/Navigation/The_future_-_Galileo/Galileo_on_the_ground

Location of Galileo centres

- Fucino Galileo Control Centre in Italy - oversee the running of navigation services
- Oberpfaffenhofen Galileo Control Centre in Germany – satellite control
- ESOC in Darmstadt, Germany – Launch and Early Operations Phase (LEOP),
- CNES (*Centre national d'études spatiales)* in Toulouse, France – provides support for launcher and satellite preparation, LEOP centre
- Redu in Belgium – In-Orbit Test campaign

Galileo subsystems - summary



Source: http://download.esa.int/docs/Galileo_IOV_Launch/Galileo_factsheet_2012.pdf

LEOP – launch and early operations

Galileo services

- Open Service (OS)
- Safety of Life (SoL)
- Commercial Service (CS)
- Public Regulated Service (PRS)
- Search and Rescue (SAR)

Open Service (OS)

- mass usage, provides position and time, free of user charge, does not require authorization, better parameters than GPS

	one frequency	two frequencies
Horizontal accuracy (95%)	15 m	4 m
Vertical accuracy (95%)	35 m	8 m
Speed meassurement accuracy (95%)	0,5 m/s	0,2 m/s
Availability	> 99,8 %	
Integrity and continuity	Not guaranteed	

Safety of Life service (SoL)

- application related to the emergency services, high integrity (air transport, railway transport, etc.)
- necessary certification of service and receiver, digital signature of the operator
- provides up-to-date warnings to the user in case certain lparameter limits are crossed (e.g. Integrity)
- guaranteed service

Safety of Life service (SoL)

		critical level
Receiver		2- or 3- frequency
Horizontal accuracy (95%)		4 m
Vertical accuracy (95%)		8 m
Accuracy of speed measurement		0,2 m/s
Integrity	Alert limit	12 m horizontal 20 m vertical
	Time to alert	6 s
	Integrity loosing risk	$3,5 . 10^{-7}$ / 150 s
Service discontinuity risk		$8 . 10^{-6}$ / 15 s
Certification and service guaranty		ensured
Integrity availability		> 99,5 %
Accuracy availability		> 99,8 %

Commercial Service (CS)

- commercial service requiring higher performance parameters than the Open Service (OS)
- for a fee services with additional value will be available, possible usage of data link
- provides access to two additional signals, to allow for a higher data throughput rate and to enable users to improve accuracy. The signals are encrypted
- CS parameters not yet finally defined

Public Regulated Service (PRS)

- provides position and timing to specific users requiring a high continuity of service, with controlled access. Two PRS navigation signals with encrypted ranging codes and data will be available
- controlled access services for government and military
- usage: police, emergency services, army, customs service, etc.
- autorization at the government level, with regards to the Europen security protocols,
- continous operation, sspecial measures to protect the reliability of the signal

Public Regulated Service (PRS)

Horizontal accuracy (95%)		6,5 m
Vertical accuracy (95%)		12 m
Speed measurement accuracy (95%)		0,2 m/s
	Alert limit	20 m horizontal 35 m vertical
Integrity	Time to alert	6 s
	Loosing integrity risk	$3,5 . 10^{-7}$ / 150 s
Service discontinuity risk		10^{-5} / 15 s
Certification and service guaranty		ensured
Availability		> 99,5 %

Search and Rescue (SAR)

- contribution to the international cooperative effort on the humanitarian search and rescue
- using current COSPAS-SARSAT system (4 Low Earth Orbit and 3 geostationary satellites) integration with the Galileo system
- improvements in the existing system
  - near real-time reception of distress messages from anywhere on Earth (the average waiting time is currently an hour);
  - precise location of alerts (a few meters, instead of the currently specified 5 km);
  - multiple satellite detection to overcome terrain blockage in severe conditions;
  - etc.

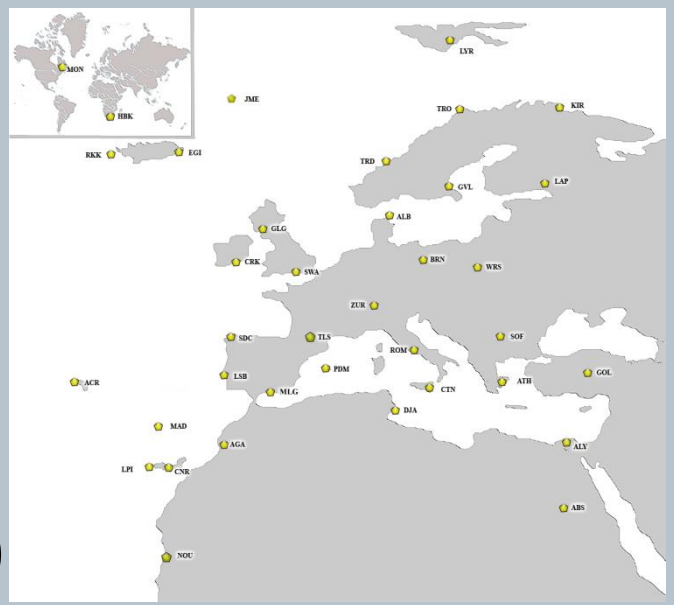
EGNOS system

EGNOS (European Geostationary Navigation Overlay Service)

- Satellite Based Augmentation System
- initiative of EC, Eurocontrol, ESA,
- information support of GPS, GLONASS and GALILEO particularly by sending differential corrections
- stations receive navigation signals and using EGNOS satellites send the more precise signal to the users
- vertical accuracy of GPS (app. 20m) is improved to 1,5 m
- usage in air transport – increases security of small planes
- officially started October 2009

EGNOS components

- ground stations – placed in Europe and around,
  - 34 ranging and integrity monitoring stations (RIMS) - pick up GNSS signals,
  - 6 navigation land earth stations (NLES)
  - 4 mission control centres (MCC) - process the data delivered by the RIMS
  - uplink stations
- 3 geostationary satellites in equatorial position to relay the signal back to users on the ground
- update of the system is planned (upgrade to version EGNOS v3 (using GPS L5 signal)



Source: http://egnos-user-support.essp-sas.eu/egnos_ops/service_performances/local/gps_vs_gps-egnos

EGNOS function

- Open Service
  - improves the accuracy of GPS to within one to two metres
  - available more than 99 percent of the time
- Safety of Life Service
  - provides the stringent integrity, continuity and availability required to support Civil Aviation applications up to LPV (Localizer Performance with Vertical guidance) operations
  - certified since March 2011
- Commercial service (so far using the Open Service)

Source: http://egnos-user-support.essp-sas.eu/egnos_ops/service_performances/local/gps_vs_gps-egnos

Other satellite- based augmentation systems (SBAS)

- USA – Wide Area Augmentation System (WAAS)
- Japan – Multi-functional Satellite Augmentation System (MSAS)
- Future systems:
  - India – launched its own SBAS programme named GPS and GEO Augmented Navigation (GAGAN) to cover the Indian subcontinent.
  - Both Korea (2013) and China (2014) have announced plans to start their own SBAS implementation.

Source: http://www.egnos-portal.eu/

Navigation systems
- legal aspects

Zuzana Bělinová
Faculty of Transportation Sciences, Czech Technical University in Prague

History of GNSS as free service

- In the USA 1996 Presidential Decision Directive (PDD/NSTC-6) - GPS-SPS (standard positioning service) available for the foreseeable future, on a continuous, worldwide basis and free of direct user fees
  - renewed by the 2004 U.S. Space-Based Positioning, Navigation and Timing Policy
  - confirmed in 2010 by the National Space Policy
- Similarly, the Russian Federation has made a corresponding offer from full deployment of GLONASS in 1995

Liability for the service

- none of the provider states accepts liability for damages occurred due to the use of their satellite system
- draft agreement deals with responsibility and liability for services (technically)
- No liability for economic compensation for damages (NCAA, 1997).

Navigation systems applications

Zuzana Bělinová
Faculty of Transportation Sciences, Czech Technical University in Prague

Satellite navigation applications in road transport

- Navigation systems – (passive navigation - CD ROM, active navigation - on-board, on-line)
- Security systems – emergency calls, stolen vehicle tracking, route optimization for emergency services, monitoring of dangerous goods,
- Preference systems – public transport and emergency vehicle preference
- Electronic charging systems – virtual detectors, paying for used sectors
- Automatic cruise control systems, anti-collision systems
- Transport modelling systems – using floating cars monitoring, travel time measurement
- Fleet management systems

Applications in road transportation – regarding parameters

- **monitoring and maintenance control** of transport infrastructures (regarding the system requirements: achieving exact infrastructure description, cohesion of GIS systems, achieving high static position accuracy)
- **monitoring of men and goods movement** (regarding the system requirements: transmission and central processing of large amount of data from sources with different accuracy)
- **charging usage of road infrastructure** (regarding the system parameters: reliability, integrity, time to response, etc.) – GNSS system is used for determination of fees

Applications in road transportation – for vehicles

- **Ensuring movement** of transport vehicle (regarding the GNSS parameters: ensuring accuracy, reliability, availability, integrity, etc in particular parts of traffic road)

- **Navigation** of transport vehicle (regarding the GNSS: signal coverage, time to response for on-line navigation, requirements on map inputs, requirements on time of data processing, etc.)

Satellite navigation applications in railway transport

- Non-safe GNSS applications
  - for traffic control as additional information
  - for use during operation closure
  - for control of timetable keeping
  - for electricity usage planning
  - for localization of failures
  - for planning of vehicle running cycles
  - additional information for automatic train operation

Satellite navigation applications in railway transport

- Safe GNSS applications
  - for working in the railyard (warning in advance of coming trains)
  - for controlling train velocity
  - for shortening the dragging sector of grade crossing
  - for navigation to place of accident
  - for creating train passages
  - for preventing counter rides
  - for preventing accidents with operational trains and other rail vehicles due to timely localisation

Satellite navigation applications in multi-modal transport

- Plans for checking-out ships, trains, trailers, etc. based on on-line information
- Loading and unloading plans and control of loading and unloading
- Planning of efficient terminal use
- Planning of stowage places for different kinds and types of containers
- Routing optimization and control for container transfer devices
- Systems for handling and manipulation with dangerous goods
- Optimization of loading/unloading processes
- Complementation of containers
- Systems for control support (management information systems)

Satellite navigation applications in air transport

- Flight in approaching areas – for some airports approaches using GPS as emergency auxiliary system are published
- Monitoring of plane movements on the Earth (besides the primary and secondary radar systems)
- Planning and rescue – quicker detection of accident location
- CNS/ATM concept (Communication, Navigation, Surveillance /Air Traffic Management) – long-time program of technical securing development – GNSS systems are part of navigation systems and also communication systems

Satellite navigation applications in air transport

- Satellite navigation as part of en-route navigation
  - Free Route – means a specific airspace within which users shall freely plan their routes between an entry point and an exit point without reference to the Air Traffic Services (ATS) route network. In this airspace, flights will remain subject to air traffic control.
    Free route concept decreases flight times and increases utilization possibilities of air space
  - Free Flight - gives the responsibility to the pilot in control to choose optimal route (e.g. to change trajectory in mid-flight) with the aid of computer systems and/or ATC (air traffic control) that provides information or warnings
    Traffic is shown on displays, full responsibility is up to the crew (contrary to the free route concept)

Thank you for your attention

References

- http://download.esa.int/docs/Galileo_IOV_Launch/BR-297_Galileo_web.pdf
- http://www.esa.int/esaNA/galileo.html
- http://ec.europa.eu/dgs/energy_transport/galileo/intro/index_en.htm
- http://gps.losangeles.af.mil/
- Up-to date information about GLONASS a GPS: http://www.glonass-ianc.rsa.ru/pls/htmldb/f?p=202:20:8186700190239 07::NO
- Global Positioning System (GPS) Standard Positioning Service (SPS) Performance Analysis Report submitted to Federal Aviation Administration by William J. Hughes Technical Center e.g. Report 76 from January 31, 2012 http://www.nstb.tc.faa.gov/REPORTS/PAN76_0112.pdf