Satellite Networks
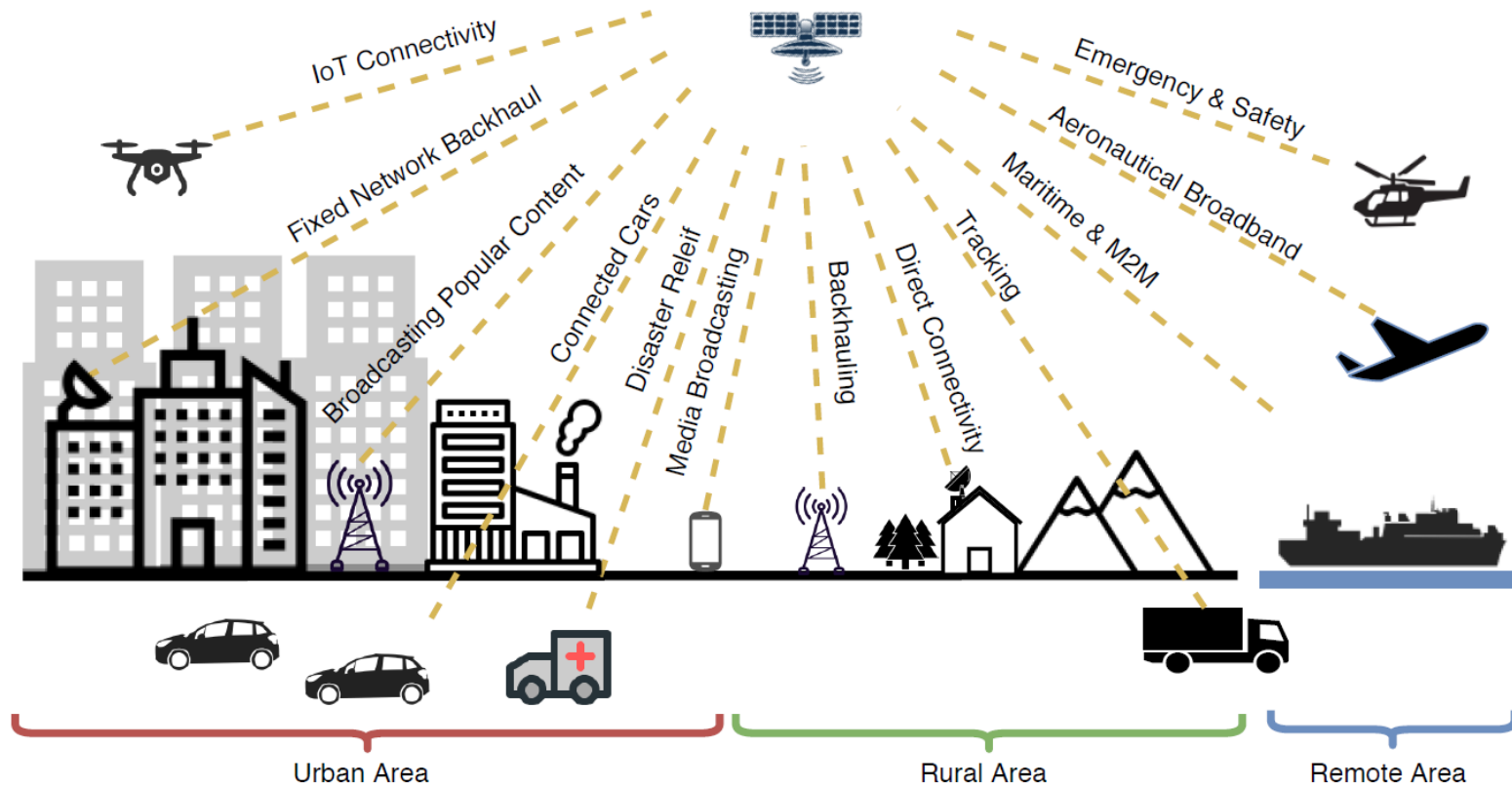# Wireless Sensor Networks

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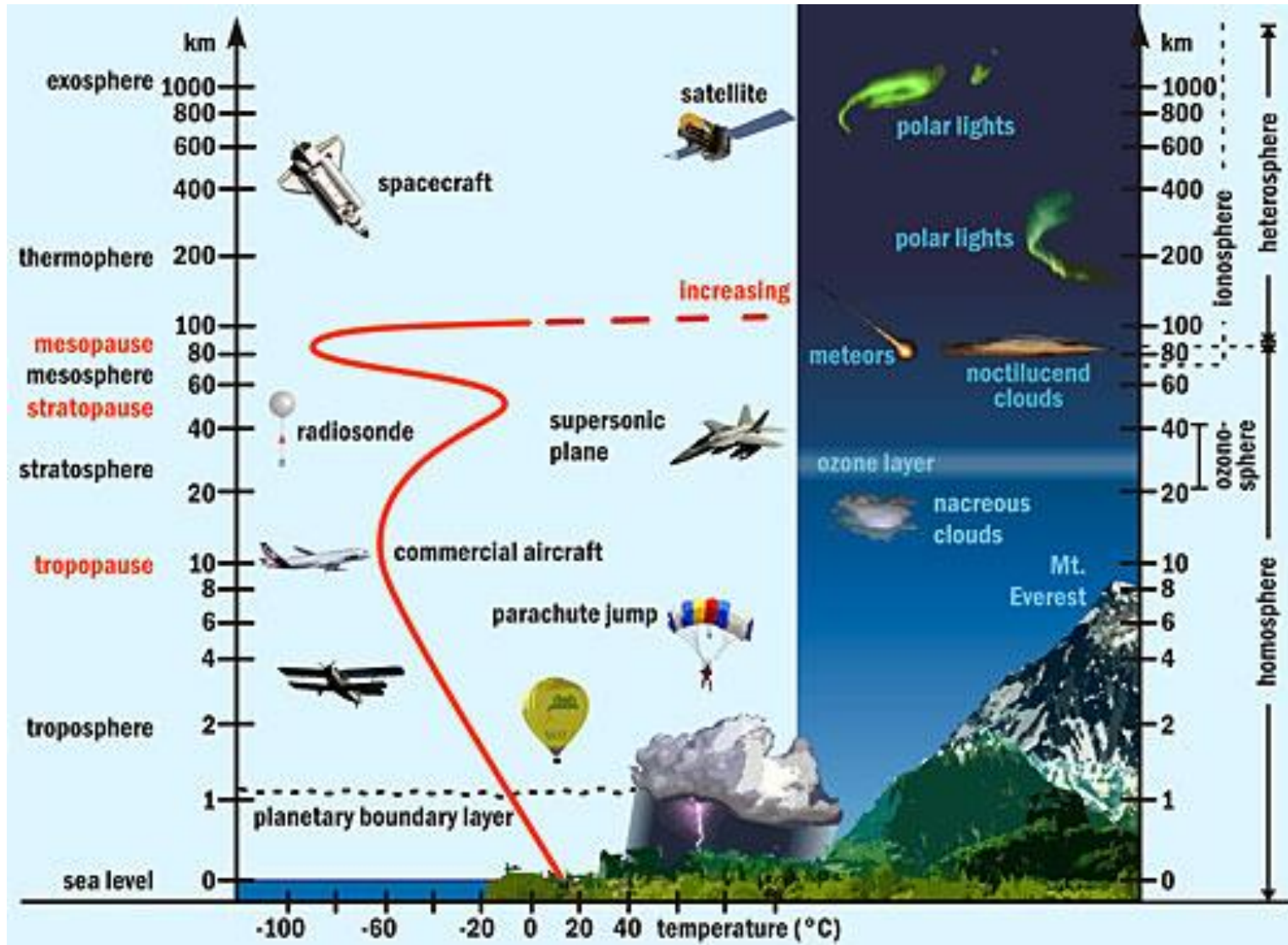
Satellite networks

SATELLITES

Distance: 378.000 km
Period: 27.3 days

IoT Connectivity

Fixed Network Backhaul

Broadcasting Popular Content

Connected Cars

Disaster Releif

Media Broadcasting

Backhauling

Direct Connectivity

Tracking

Maritime & M2M

Aeronautical Broadband

Emergency & Safety
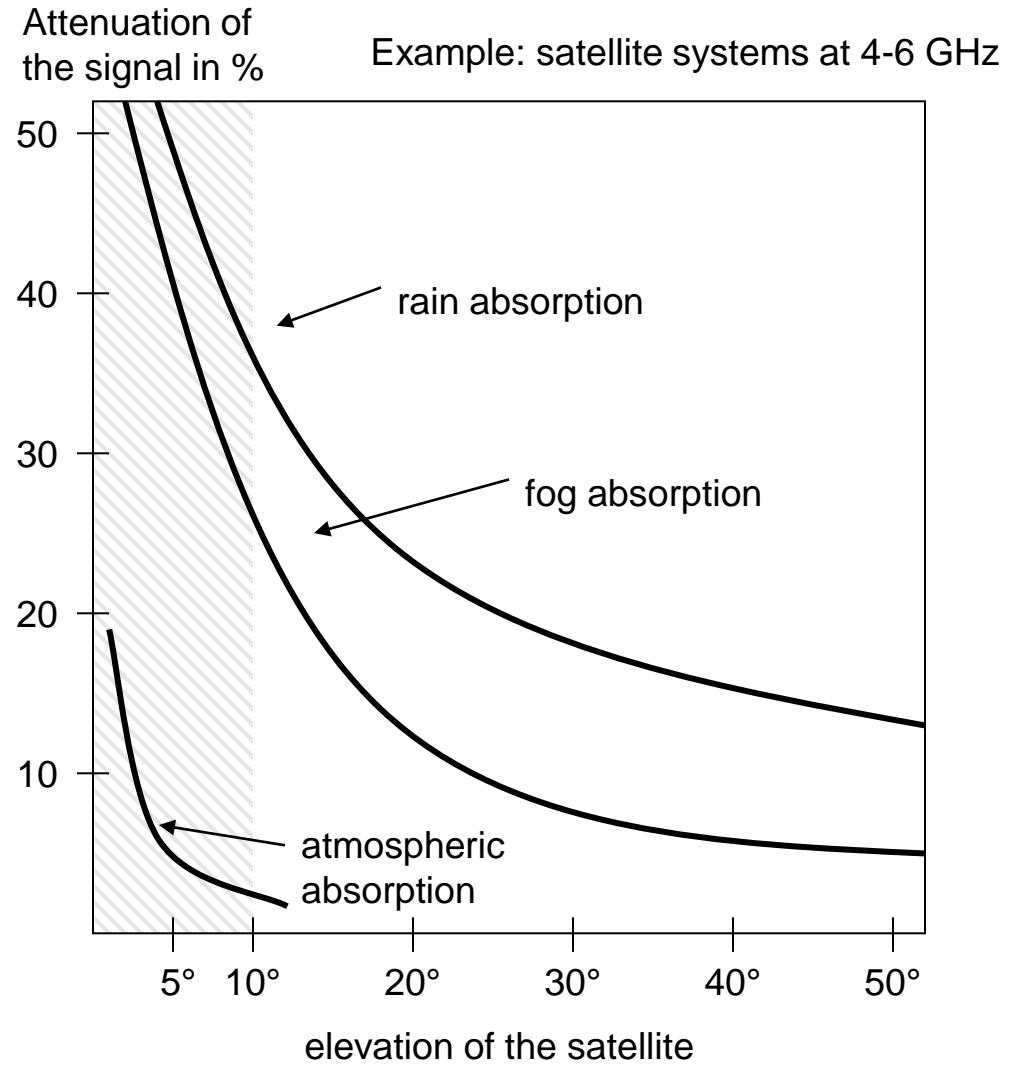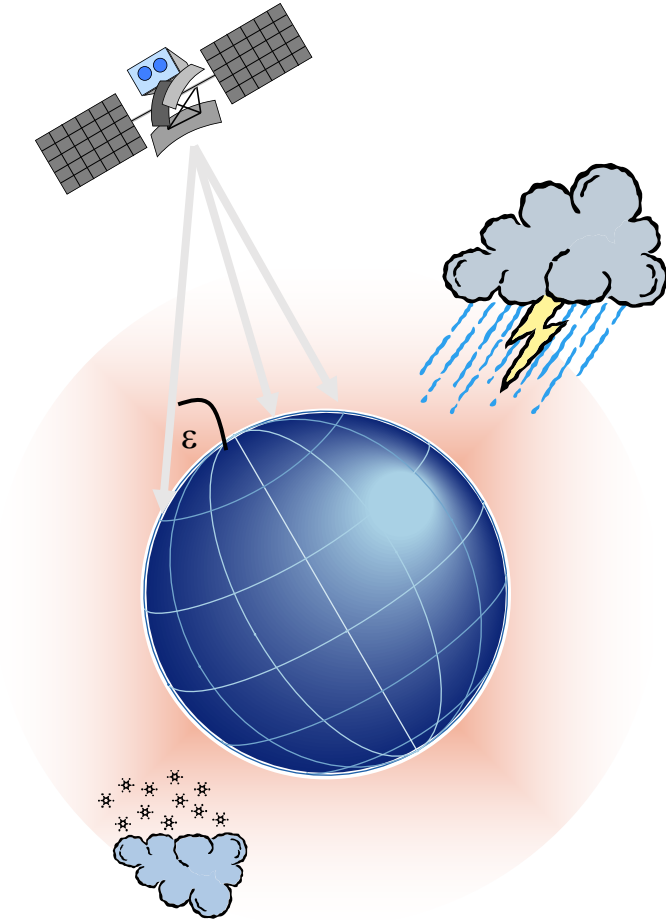
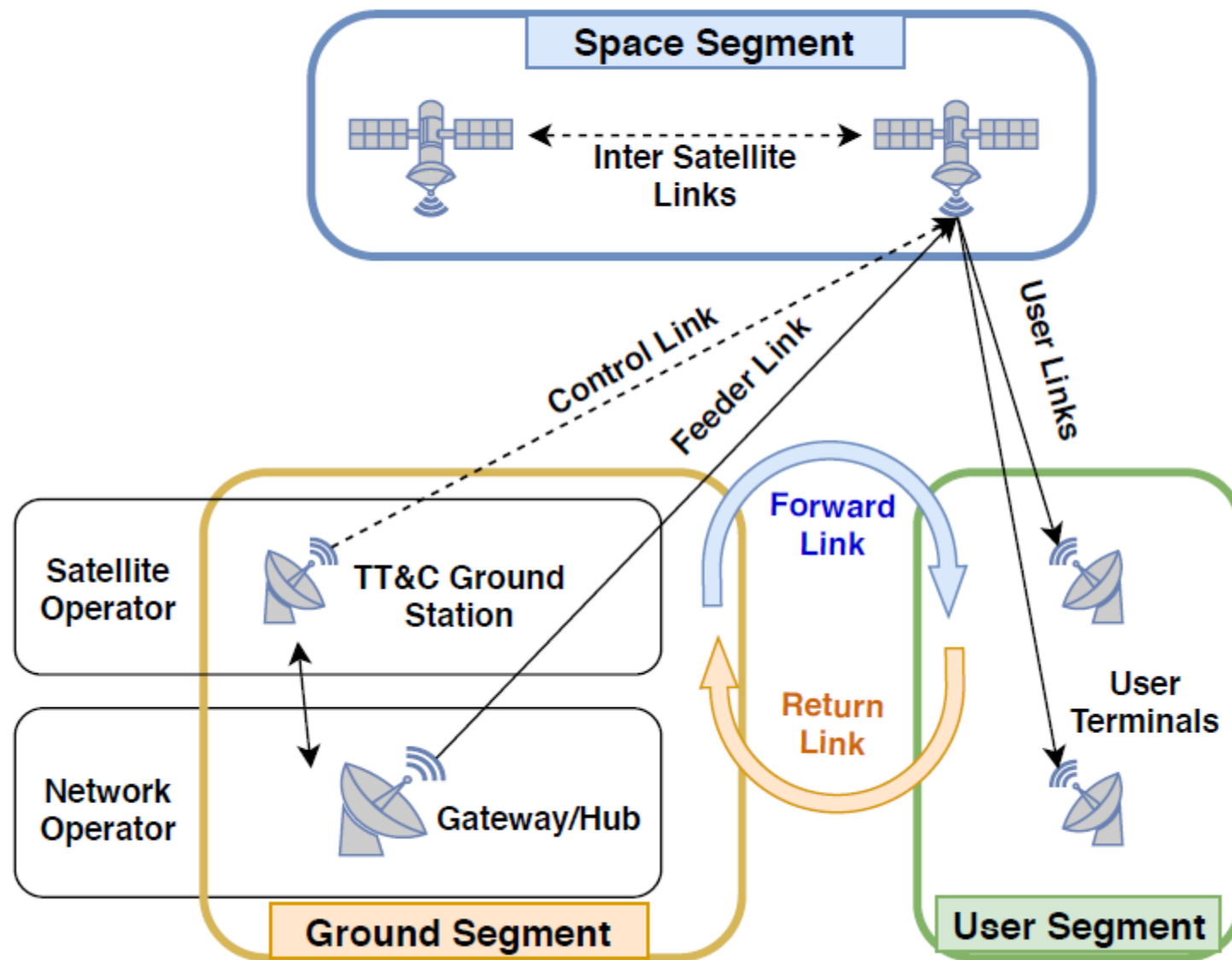Urban Area

Rural Area

Remote Area

Earth's atmosphere

Basics

❑ elliptical or circular orbits

❑ complete rotation time depends on distance satellite-earth

❑ inclination: angle between orbit and equator

❑ elevation: angle between satellite and horizon

❑ LOS (Line of Sight) to the satellite necessary for connection
➔ high elevation needed, less absorption due to e.g. buildings

❑ Uplink: connection base station - satellite

❑ Downlink: connection satellite - base station

❑ typically separated frequencies for uplink and downlink
- transponder used for sending/receiving and shifting of frequencies
- transparent transponder: only shift of frequencies
- regenerative transponder: additionally signal regeneration

Features of Satellite Networks

- Effects of satellite mobility
  - Topology is dynamic.
  - Topology changes are predictable and periodic.
  - Traffic is very dynamic and non-homogeneous.
  - Handovers are necessary.

- Limitations and capabilities of satellites
  - Power and onboard processing capability are limited.
  - Implementing the state-of-the-art technology is difficult.
  - Satellites have a broadcast nature.

- Nature of satellite constellations
  - Higher propagation delays.
  - Fixed number of nodes.
 - Highly symmetric and uniform structure.

Atmospheric attenuation

Attenuation of the signal in %

Example: satellite systems at 4-6 GHz

rain absorption

fog absorption

atmospheric absorption

elevation of the satellite

- Satellite up links and down links can operate in different frequency bands:

Frequency Bands	Downlink Channel (DL)	Uplink Channel (UL)	
L Band	1.535-1.56 GHz	1.635-1.66 GHz	Mobile/fixed comms., GPS
S Band	2.5-2.54 GHz	2.65-2.69 GHz	Direct to Sat comms
C Band	3.7-4.2 GHz	5.9-6.4 GHz	TV bcast., some Wi-Fi, phones and weather radars
X Band	7.25-7.75 GHz	7.9-8.4 GHz	Deep space comms.
Ku Band	10-13 GHz	14-17 GHz	Backhauls, TV studios
Ka Band	18-20 GHz	27-31 GHz	Radars in military planes

- The up-link is a highly directional, point to point link
- The down-link can have a footprint providing coverage for a substantial area "spot beam".
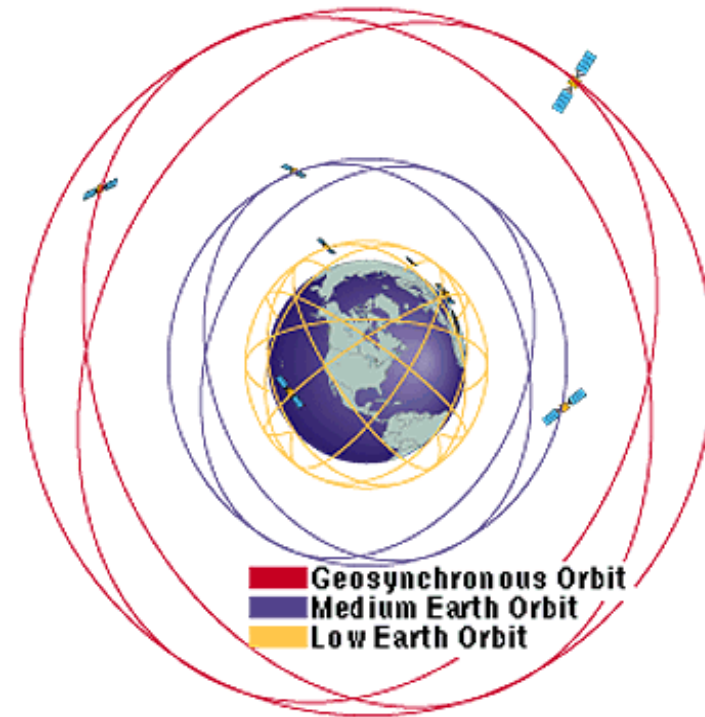
Types of Satellite Orbits

- Based on the inclination, "i", over the equatorial plane:
  - Equatorial Orbits above Earth's equator (i=0°)
  - Polar Orbits pass over both poles (i=90°)
  - Other orbits called inclined orbits (0°<i<90°)

- Based on Eccentricity
  - Circular with centre at the earth's centre
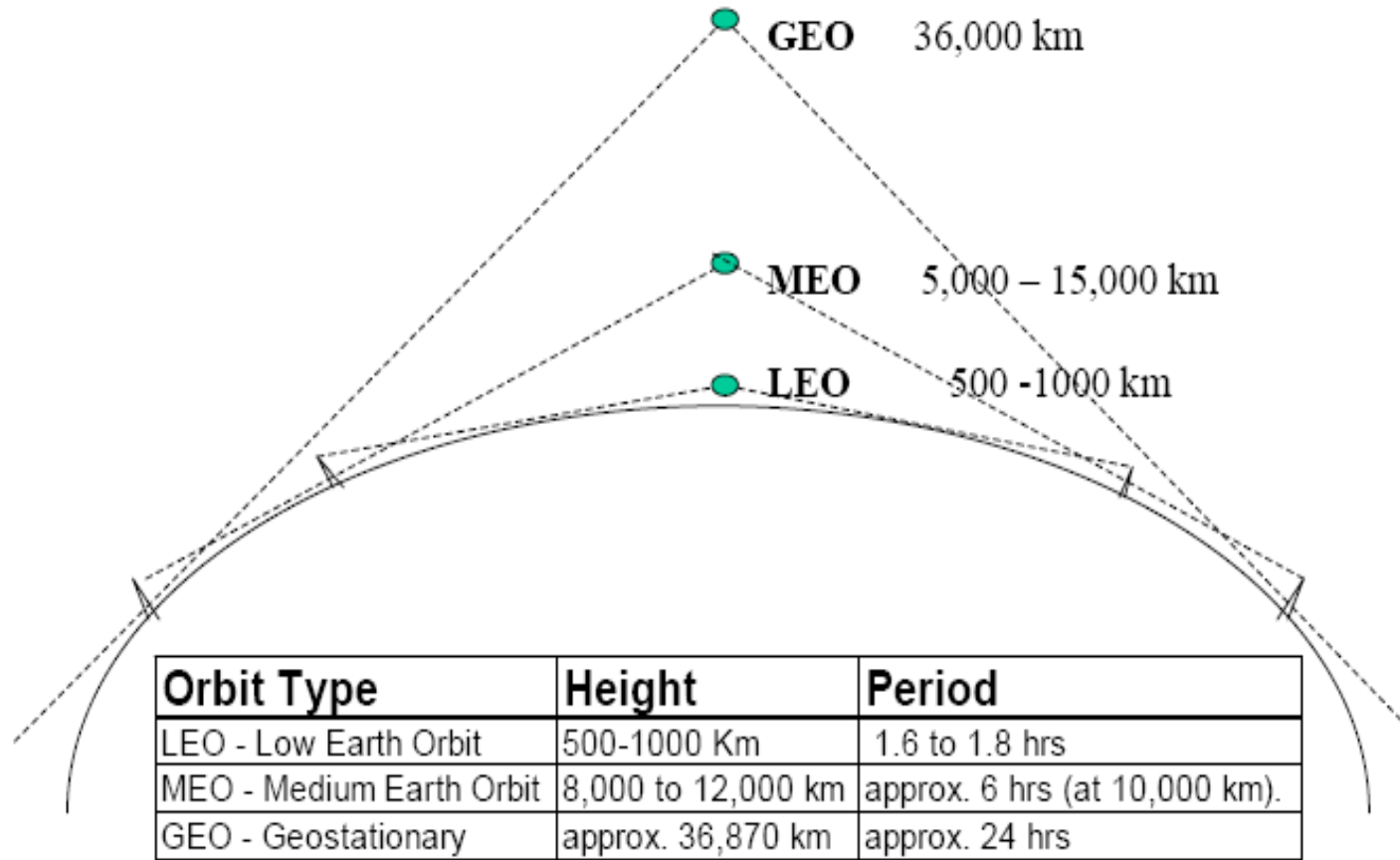 - Elliptical with one foci at earth's centre
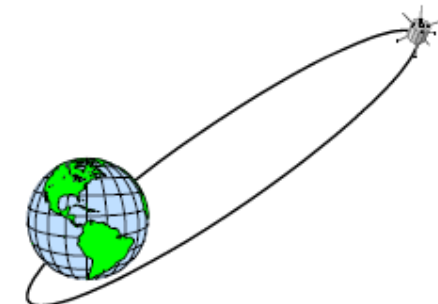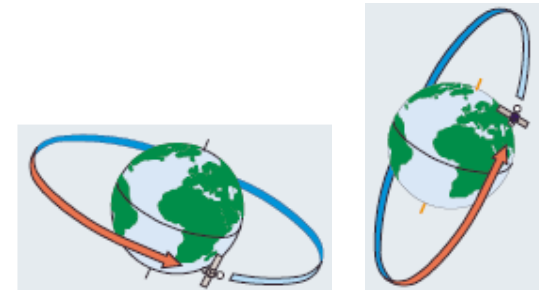
Types of Satellite based Networks

- Based on the Satellite Altitude
  - GEO – Geostationary Orbits
    - 36000 Km = 22300 Miles, equatorial, High latency
  - MEO – Medium Earth Orbits
    - High bandwidth, High power, High latency
  - LEO – Low Earth Orbits
    - Low power, Low latency, More Satellites, Small Footprint
  - VSAT
    - Very Small Aperture Satellites
   - Private WANs

Geosynchronous Orbit
Medium Earth Orbit
Low Earth Orbit

Satellite Orbits – Another perspective

GEO   36,000 km

MEO   5,000 – 15,000 km

LEO   500 -1000 km

Orbit Type	Height	Period
LEO - Low Earth Orbit	500-1000 Km	1.6 to 1.8 hrs
MEO - Medium Earth Orbit	8,000 to 12,000 km	approx. 6 hrs (at 10,000 km).
GEO - Geostationary	approx. 36,870 km	approx. 24 hrs

GEO - Geostationary Orbit

▶ In the equatorial plane

▶ Orbital Period = 23 h 56 m 4.091 s

= 1 sidereal day*

▶ Satellite appears to be stationary over any point on equator:
  ▶ Earth Rotates at same speed as Satellite
  ▶
  ▶

CM 23/24
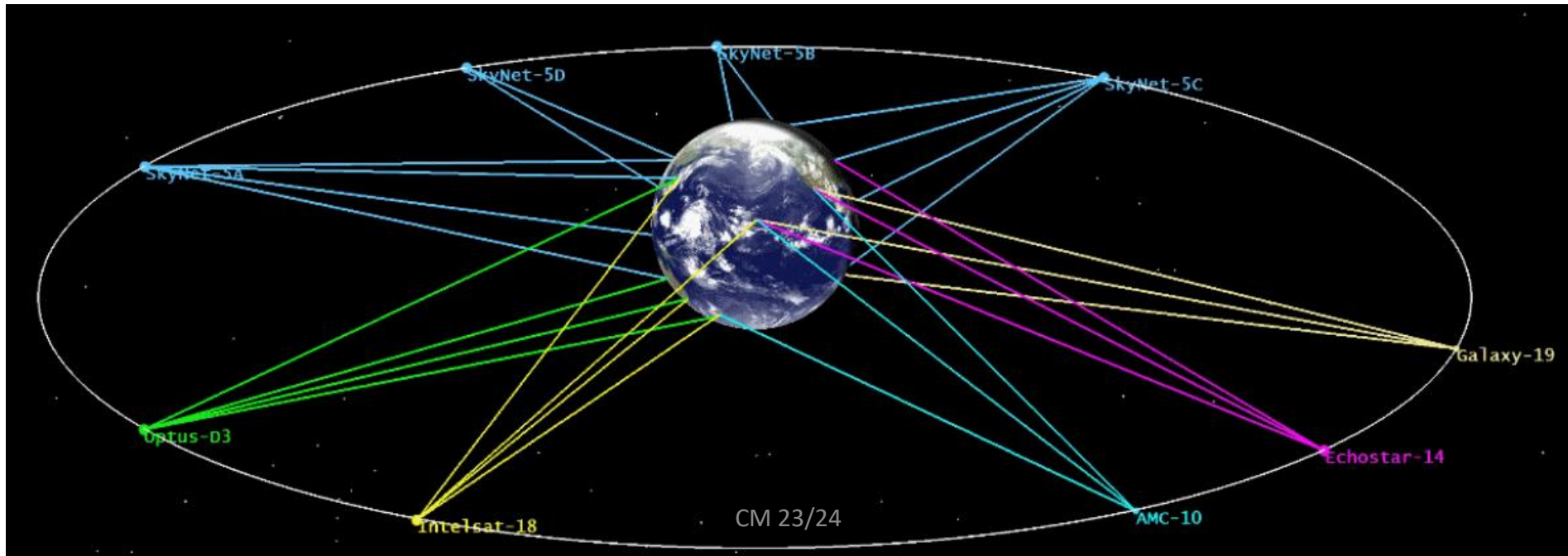
GEO Satellites

- No handover

- One-way propagation delay: 250-280 ms

- 3 to 4 satellites for global coverage

- Mostly used in video broadcasting

- Another applications:
  - Weather forecast, global communications, military applications

- Advantage: well-suited for broadcast services

- Disadvantages: Long delay, high free-space attenuation

MEO Satellites

- One-way propagation delay: 100 – 130 ms
- 10 to 15 satellites for global coverage
- Infrequent handover
- Orbit period: ~6 hr
- Mostly used in navigation
  - GPS, Galileo, Glonass
- Communications: Inmarsat, ICO

MEO Example: GPS

visible sat = 12

- Global Positioning System
  - Developed by US Dept. Of Defence
  - Became fully operational in 1993
  - Currently 31 satellites at 20.200 km.
    - Last lunch: March 2008

- It works based on a geometric principle
  - "Position of a point can be calculated if the distances between this point and three objects with known positions can be measured"

- Four satellites are needed to calculate the position
  - Fourth satellite is needed to correct the receiver's clock.

- Selective Availability

- Glonass (Russian): 24 satellites, 19.100 km

- Galileo (EU): 30 satellites, 23.222 km, under development (expected date: 2013)

- Beidou (China): Currently experimental & limited.
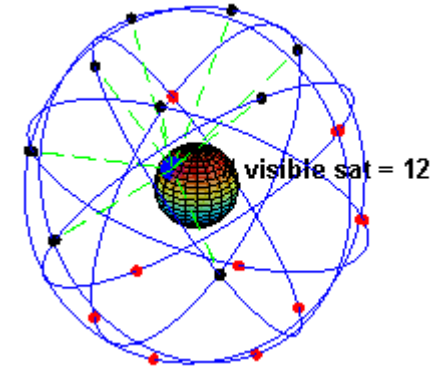
LEO - Low Earth Orbits

- Circular or inclined orbit with < 1400 km altitude
  - Satellite travels across sky from horizon to horizon in 5 - 15 minutes => needs handoff
  - Earth stations must track satellite or have Omni directional antennas
  - Large constellation of satellites is needed for continuous communication (66 satellites needed to cover earth)
  - Requires complex architecture
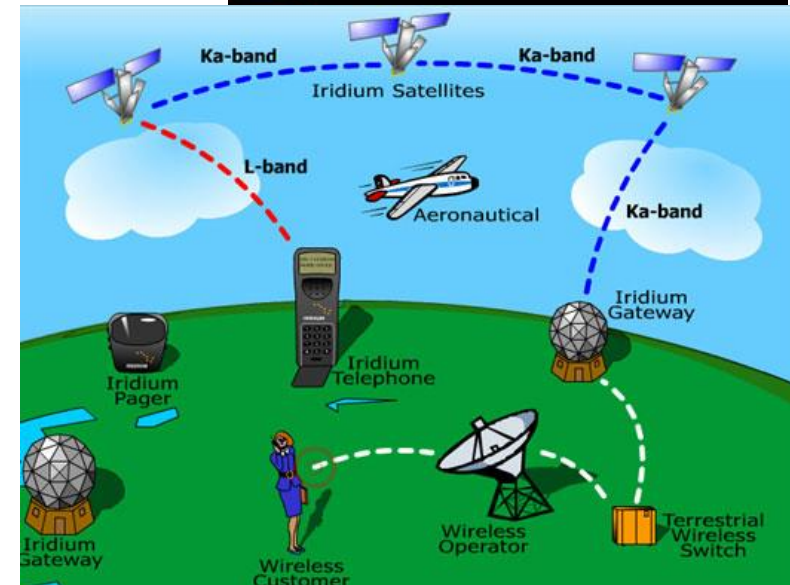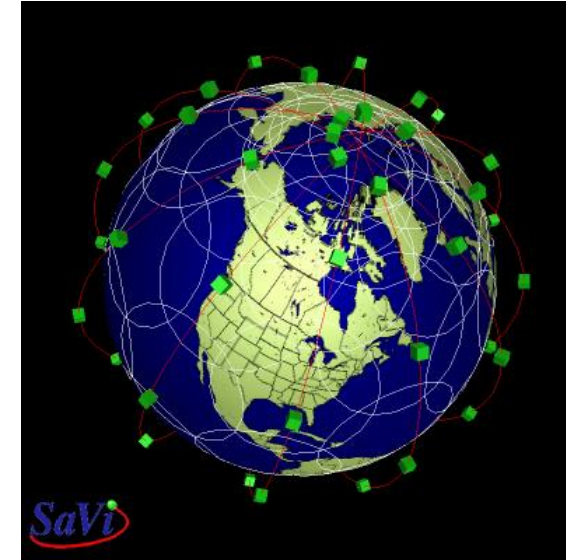 - Requires tracking at ground
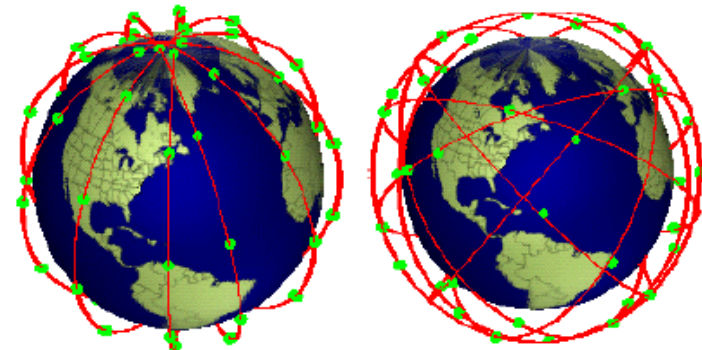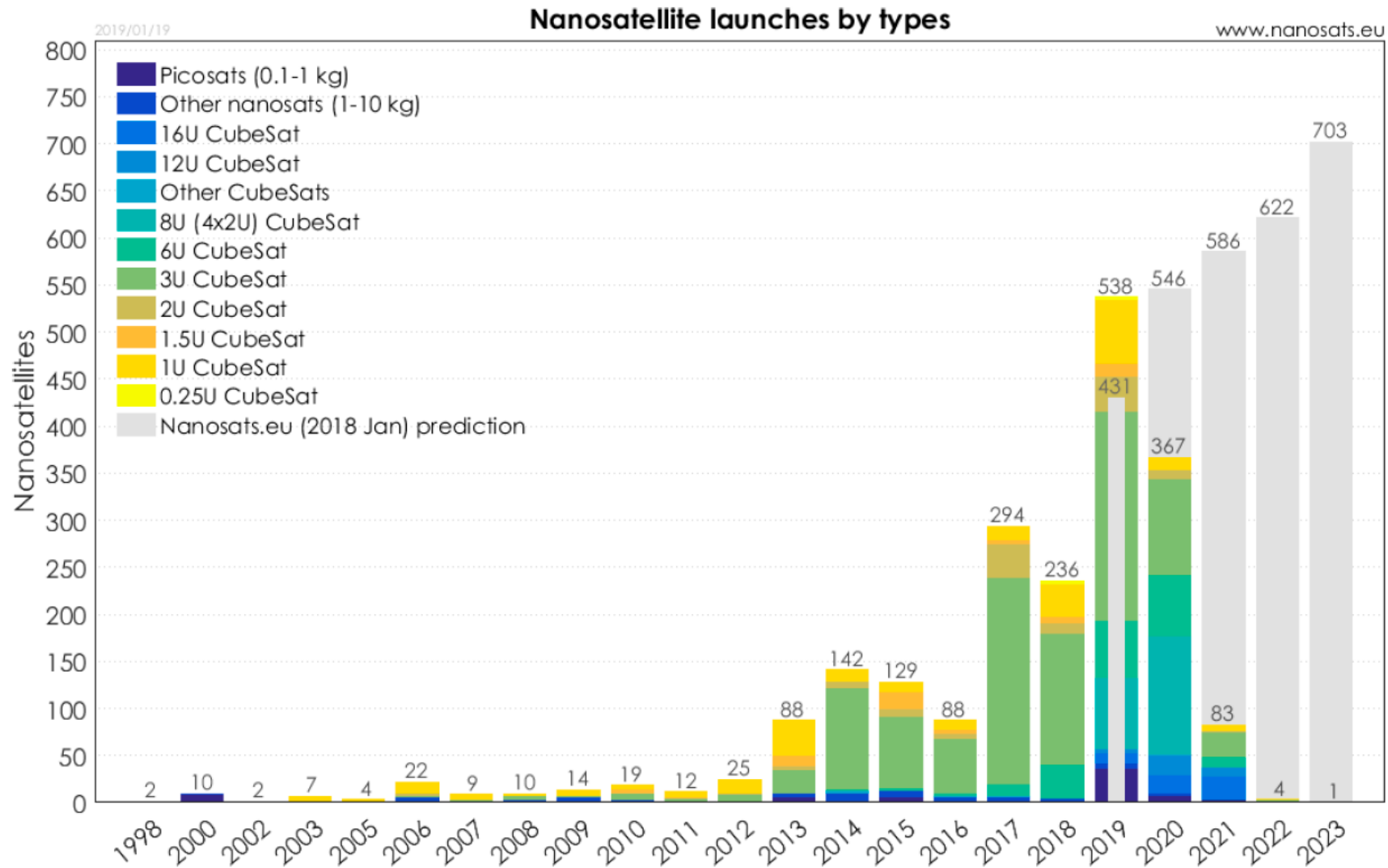
LEO Satellites

- One-way propagation delay: 5 – 20 ms

- More than 32 satellites for global coverage

- Frequent handover

- Orbit period: ~2 hr

- Applications:
  - Earth Observation
    - GoogleEarth image providers (DigitalGlobe, etc.)
    - RASAT (First satellite to be produced solely in Turkey)
  - Communications
    - Globalstar, Iridium
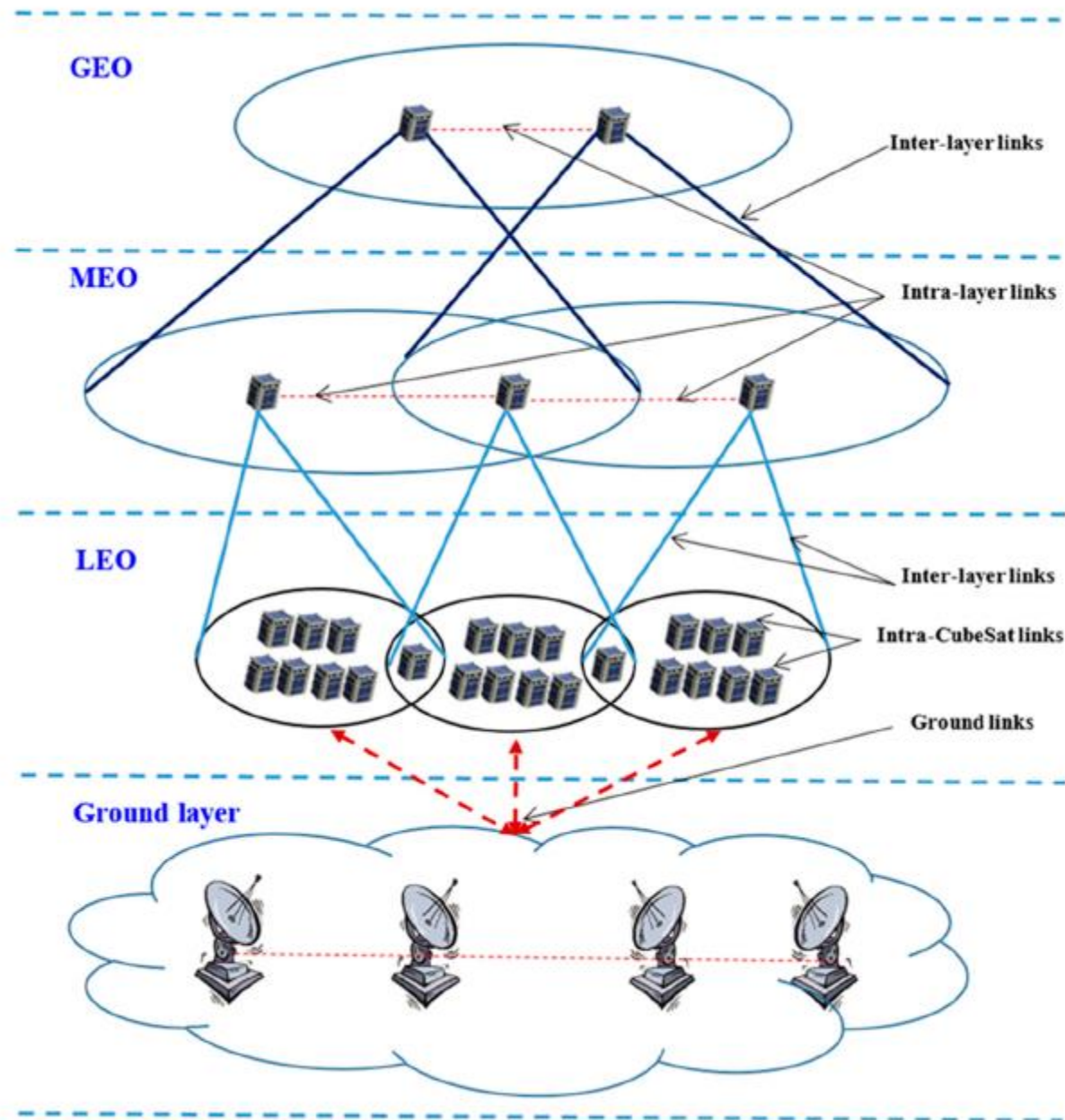 - Search and Rescue (SAR)
    - COSPAS-SARSAT

Iridium

- 66 satellites (6 planes, 11 sat per plane) and 10 spares.
- 86.4˚ inclination: full coverage
- Altitude: 780 km
- Intersatellite links, onboard processing
- Satellite visibility time: 11.1 min
- Satellites launched in 1997-98.
- Initial company went into bankrupcy
  - Technologically flawless, however:
  - Very expensive; Awful business plan
  - Cannot compete with GSM
- Now, owned by Iridium satellite LLC.
- 280.000 subscribers (as of Aug. 2008)
- Multi-year contract with US DoD.
- Satellite collision (February 10, 2009).

The cubesat explosion

Nanosatellite launches by types

2019/01/19

www.nanosats.eu

Legend:
- Picosats (0.1-1 kg)
- Other nanosats (1-10 kg)
- 16U CubeSat
- 12U CubeSat
- Other CubeSats
- 8U (4x2U) CubeSat
- 6U CubeSat
- 3U CubeSat
- 2U CubeSat
- 1.5U CubeSat
- 1U CubeSat
- 0.25U CubeSat
- Nanosats.eu (2018 Jan) prediction

Challenges	Implications
Intermittent connectivity	- Satellites on this orbit are characterized by scheduled predictable/semi-predictable intermittent connectivity, whether for a satellite to ground links or inter-satellite links. - There are no contemporary paths present for satellite and ground station communication or cross-link communication.
Orbital period	- LEO satellite orbital velocity ~= 7800 m/s, based on the satellite altitude orbital period of about 90–110 minu for 160–1200 km altitudes respectively. - Limited encounter time between satellites which in turns bounds data transfer rate.
Inter-CubeSat links	- Transmission range between two satellites, approximately 5–200 km. - The transmission range of inter-CubeSats is bound by cross-link antenna transmission power. - Limited antenna size and capability compared with the conventional satellites. - Limited antenna coverage compared with the conventional satellites.
Up/Downlinks with the ground station	- Transmission range between satellite and ground station, approximately 200–1200 km - The transmission range of CubeSats is bounded by the downlink antenna transmit power. - Satellite revisit time Limited antenna size and capability
Altitude and inclination ranges	- Orbit altitude rang is 200–1200 km above the Earth and orbit inclination ranges 0°–180°.
Natural drag	- Common de-orbiting behaviour leads to changes in orbital height and hence meeting time between CubeSats will also change over time. - Orbiting at lower altitudes increases the drag process. - The drag upsurges with increasing solar activity (sunspots).
High failure rate	- Space radiation effects on electronic components, particularly Commercial-off-the Shelf (COTS) components. - Impossibility of recovery under failure.
Energy	- Solar cells limited space available on the small size of the CubeSat body. - Small storage batteries. - High power consumption of up/downlinks and cross-links.
Topology density	- Satellite dissemination and encounter times.
CubeSat stability on orbit	- There is no space on the CubeSats for advanced stability control devices. - Antenna directionality and steering ability.
Data rate	- A single CubeSat has limited data rate - CubeSat swarms and constellations can provide a higher overall system data rate, however, networking CubeSats in these systems is challenging and requires advanced routing protocols.

GEO

Inter-layer links

MEO

Intra-layer links

LEO

Inter-layer links

Intra-CubeSat links

Ground links

Ground layer

High Altitude Platforms (HAPs)

- Aerial unmanned platforms

- Quasi-stationary position (at 17-22 km)

- Telecommunications & surveillance

- Advantages:
  - Cover larger areas than terrestrial base stations
  - No mobility problems like LEOs
  - Low propagation delay
  - Smaller and cheaper user terminals
  - Easy and incremental deployment

- Disadvantages:
  - Immature airship technology
  - Monitoring of the platform's movement

HAP-Satellite Integration
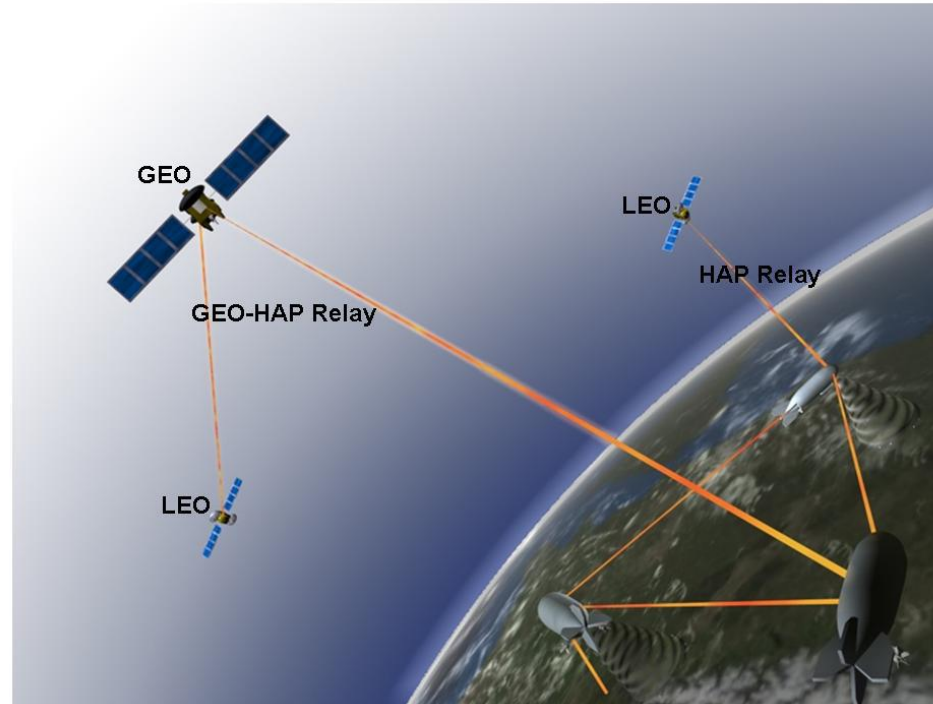
- HAPs have significant advantages.
- Satellites still represent the most attractive solution for broadcast and multicast services
- Should be considered as complementary technologies.

GEO / MEO

LEO / VLEO

HAPs

LAPs

Base
Station
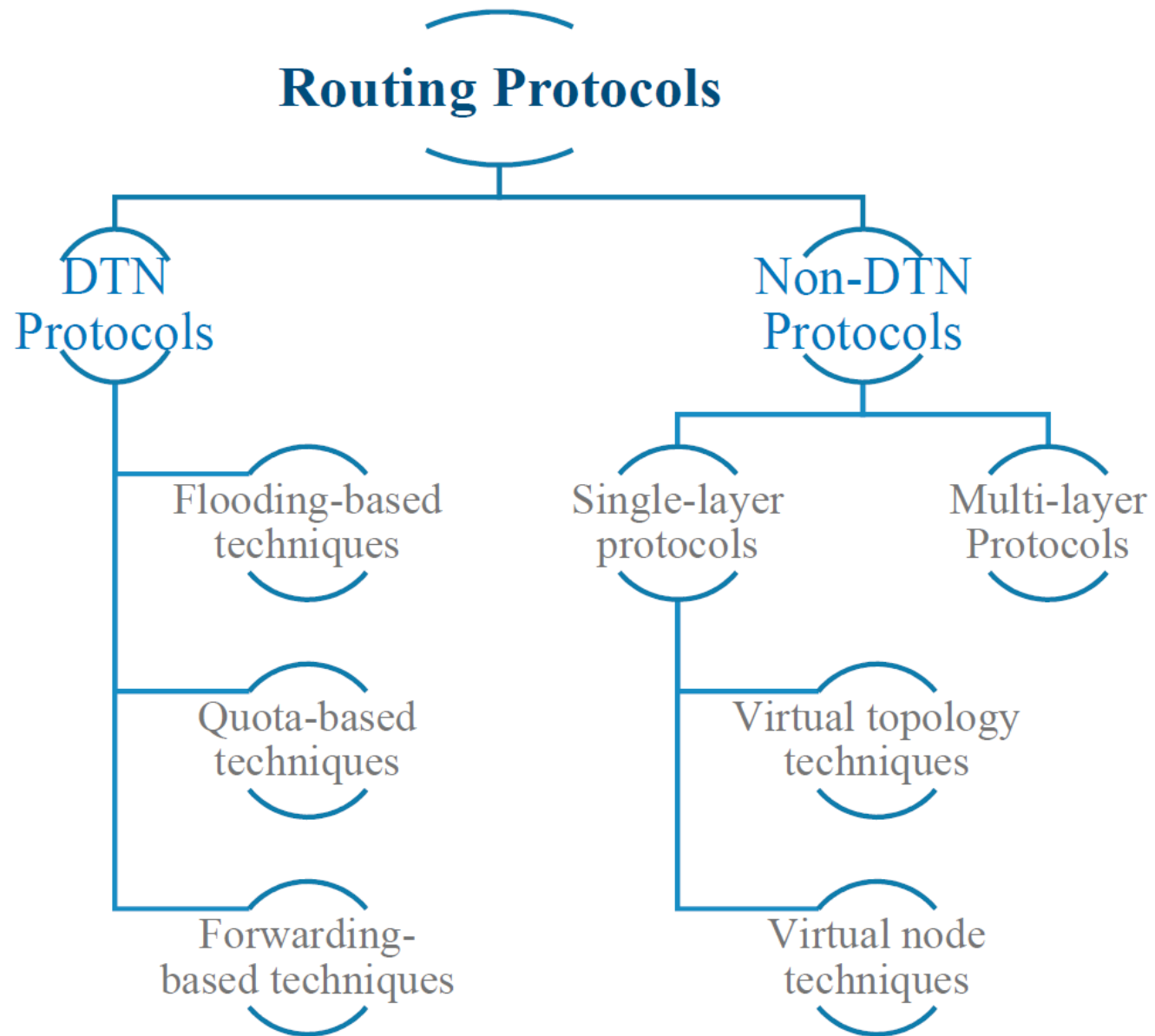
Relay
Station

Ground
Station
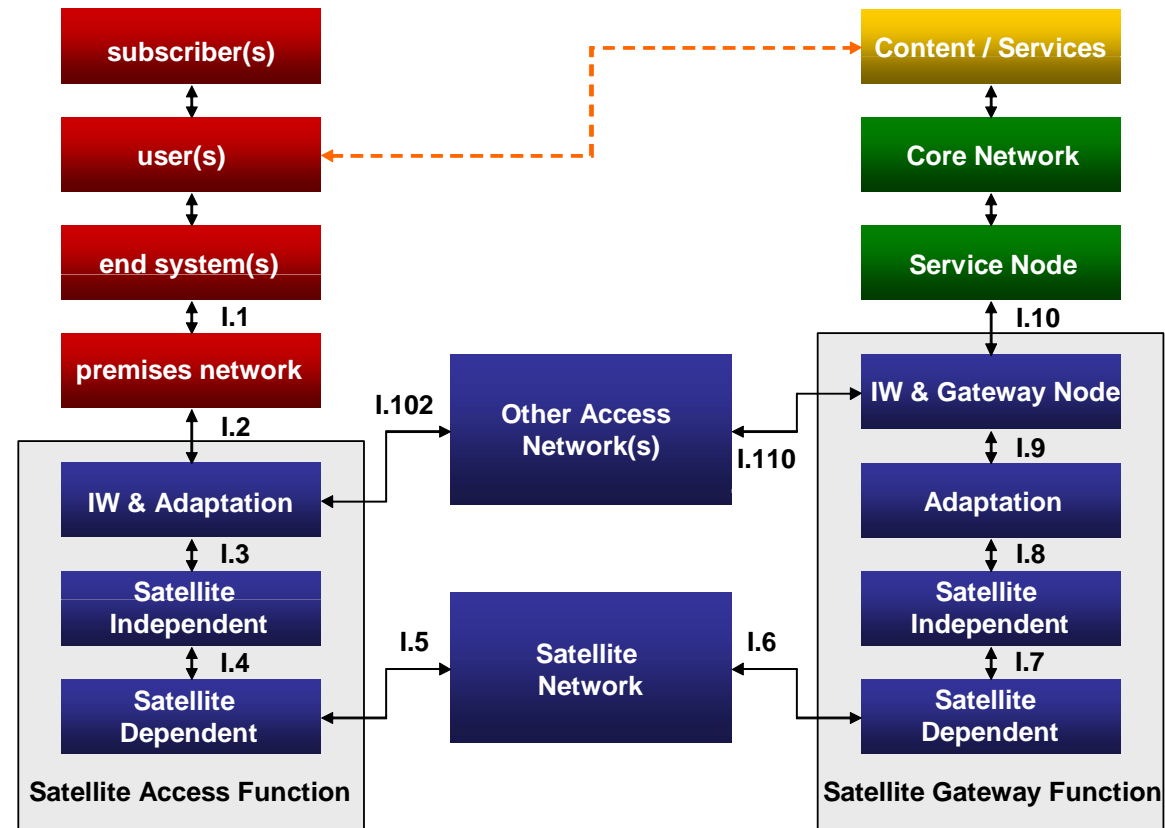
Ground
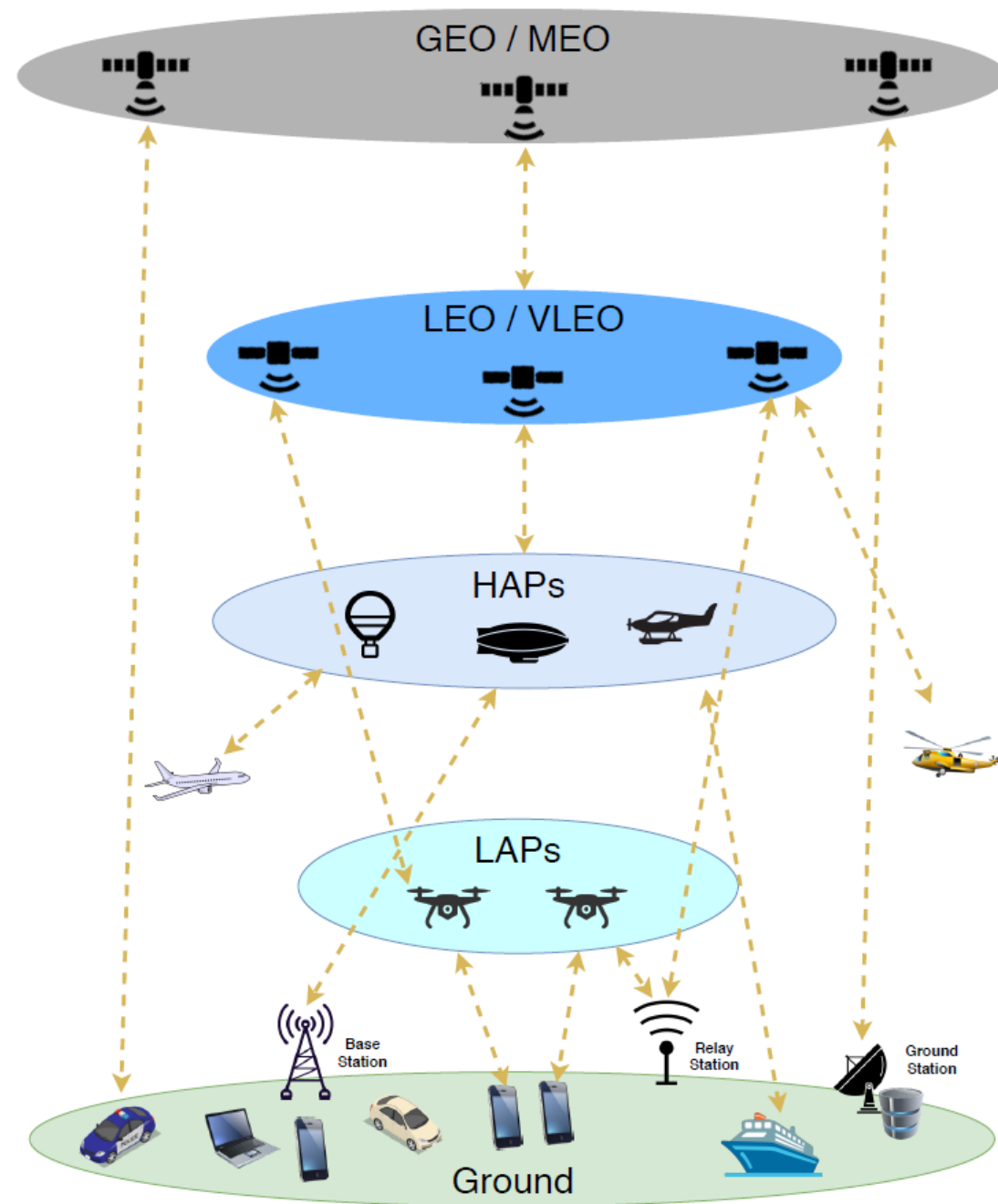
Satellites - Overview

- GEOs have good broadcasting capability, but long propagation delay.

- LEOs offer low latency, low terminal power requirements.

- Inter-satellite links and on-board processing for increased performance and better utilization of satellites
  - From flying mirrors to intelligent routers on sky.

- Major problem with LEOs: Mobility of satellites
  - Frequent hand-over

- Another important problem with satellites:
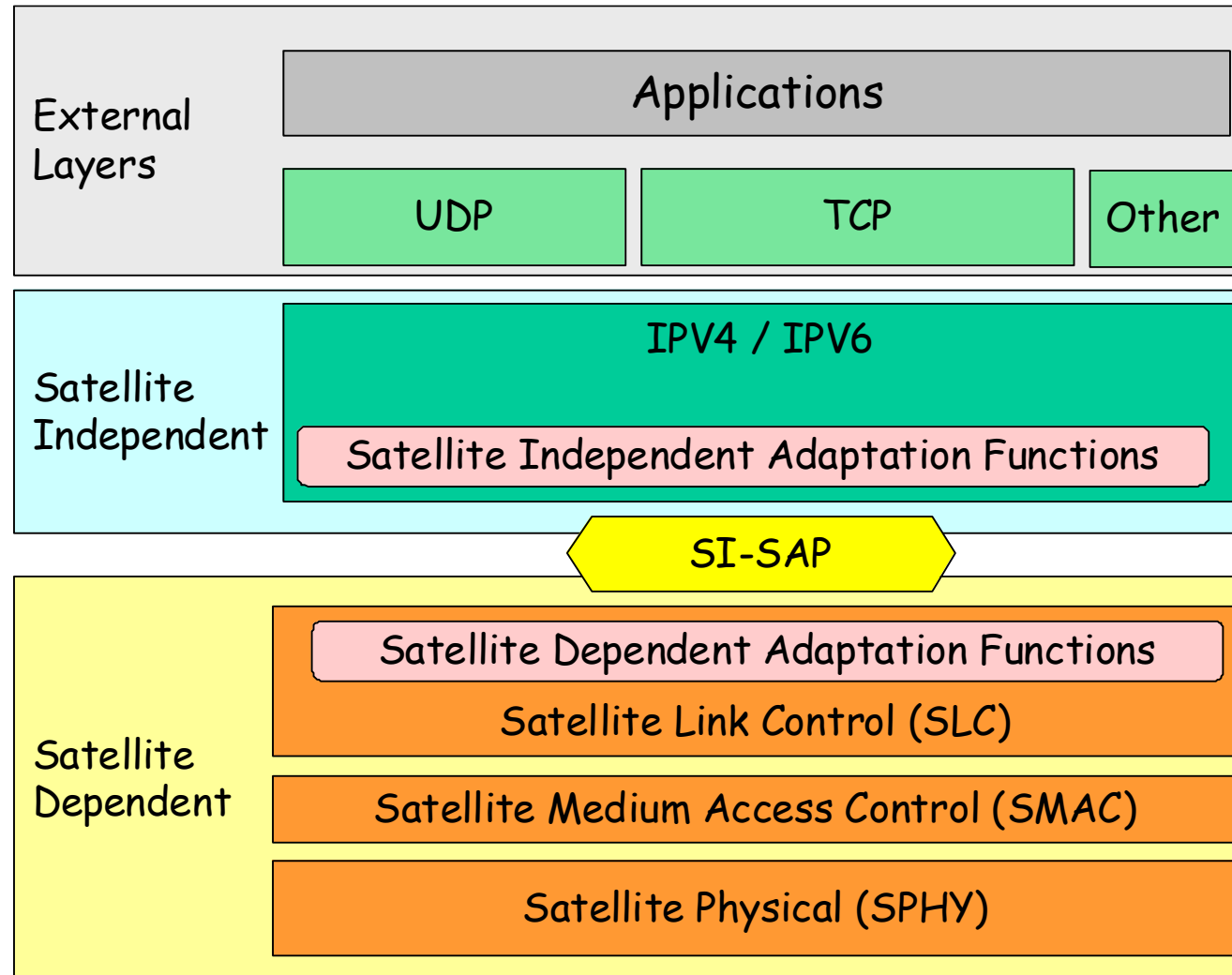 - Infeasible to upgrade the technology, after the satellite is launched

Routing

- One solution: inter satellite links (ISL)
- ❑reduced number of gateways needed
- ❑forward connections or data packets within the satellite network as long as possible
- ❑only one uplink and one downlink per direction needed for the connection of two mobile phones
- Problems:
- ❑more complex focusing of antennas between satellites
- ❑high system complexity due to moving routers
- ❑higher fuel consumption
- ❑thus shorter lifetime
- Iridium and Teledesic planned with ISL
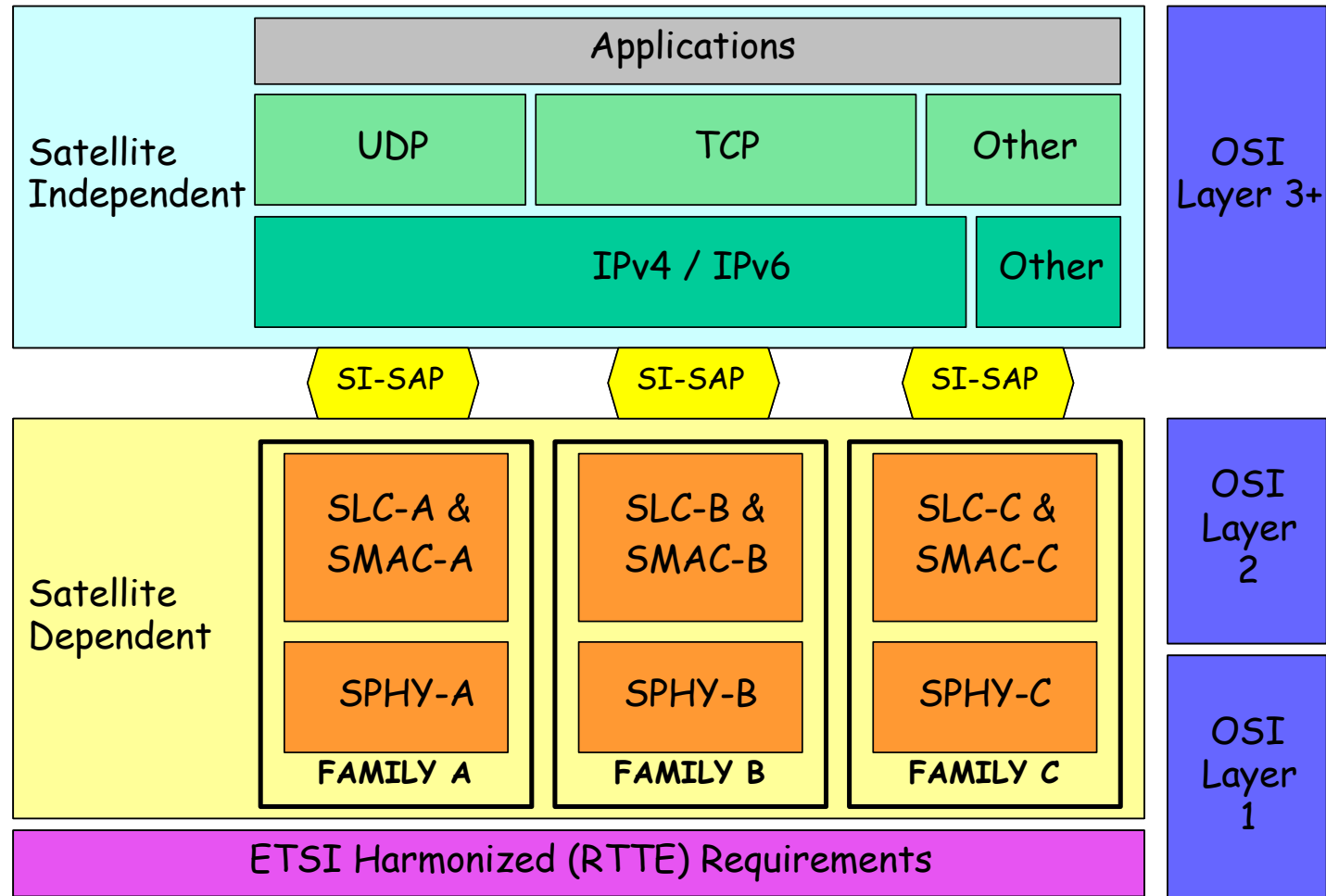- Other systems use gateways and additionally terrestrial networks
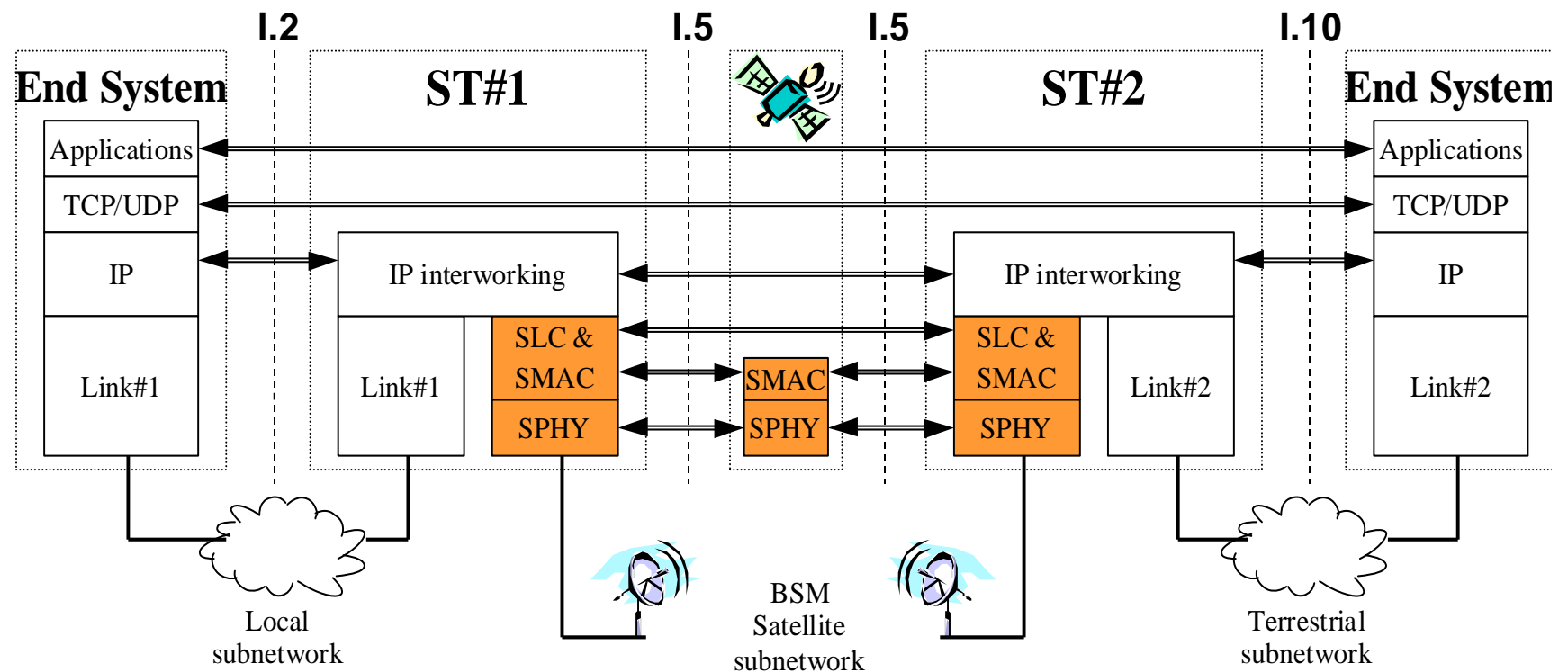
Reference model for satellite access

Protocol architecture

Protocol architecture

		Applications		
Satellite Independent	UDP	TCP	Other	OSI Layer 3+
	IPv4 / IPv6		Other	

SI-SAP   SI-SAP   SI-SAP

Satellite Dependent	SLC-A & SMAC-A	SLC-B & SMAC-B	SLC-C & SMAC-C	OSI Layer 2
	SPHY-A	SPHY-B	SPHY-C	OSI Layer 1
	FAMILY A	FAMILY B	FAMILY C	

ETSI Harmonized (RTTE) Requirements

RTTE – Radio and Telecommunications Terminal Equipment Directive

IP interworking

Wireless Sensor Networks