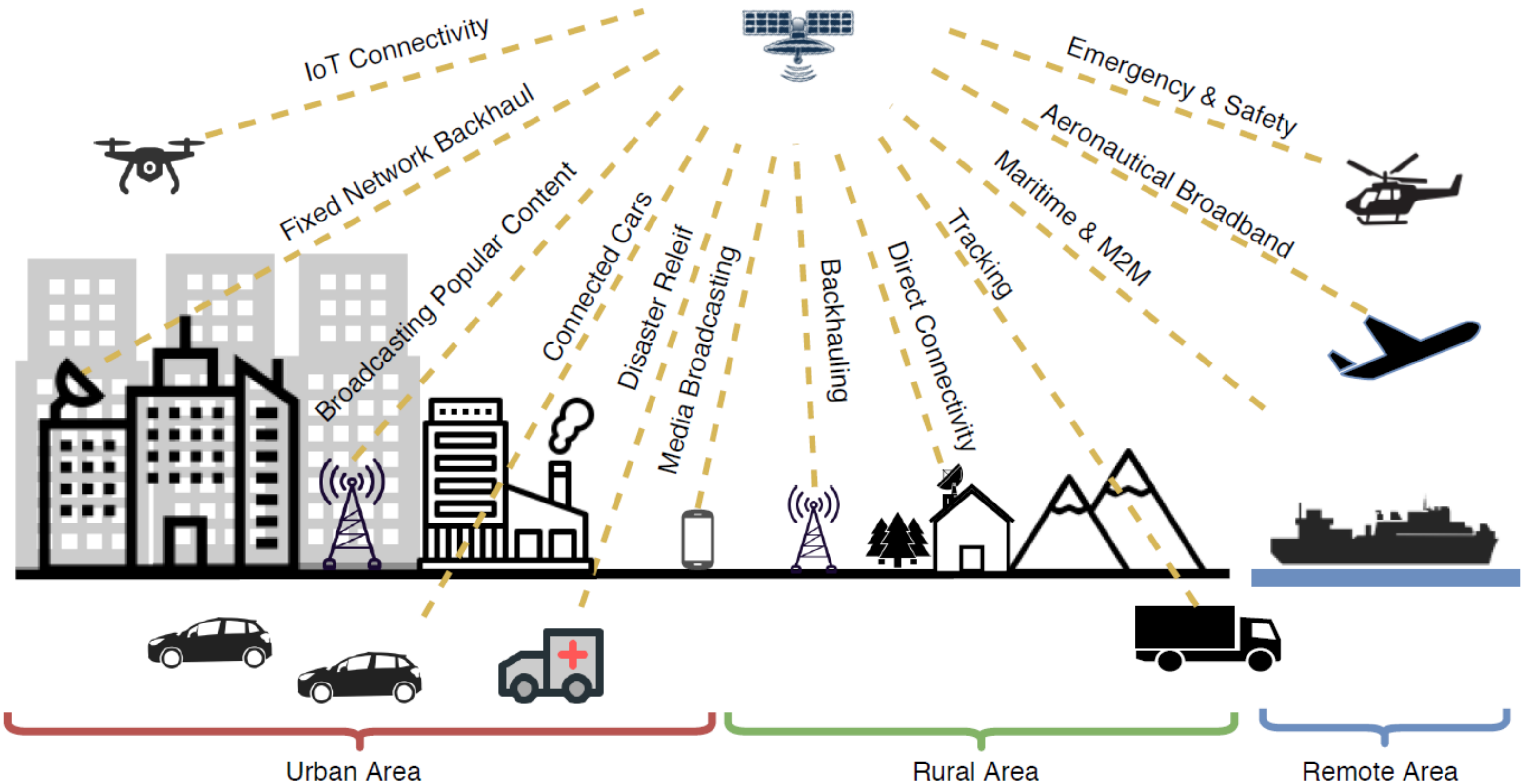
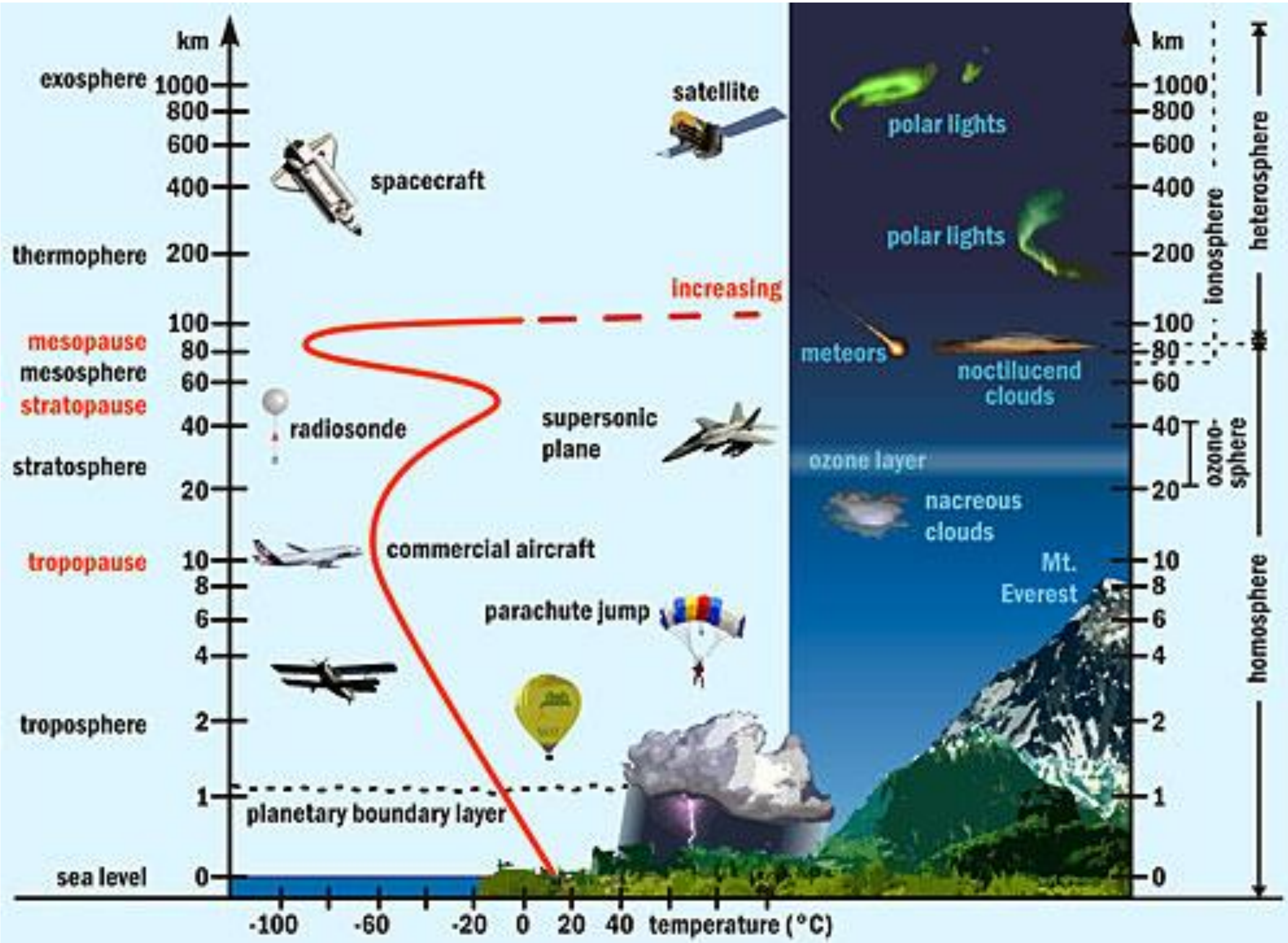
SATELLITES


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



Source: All about GPS [www.kowoma.de]

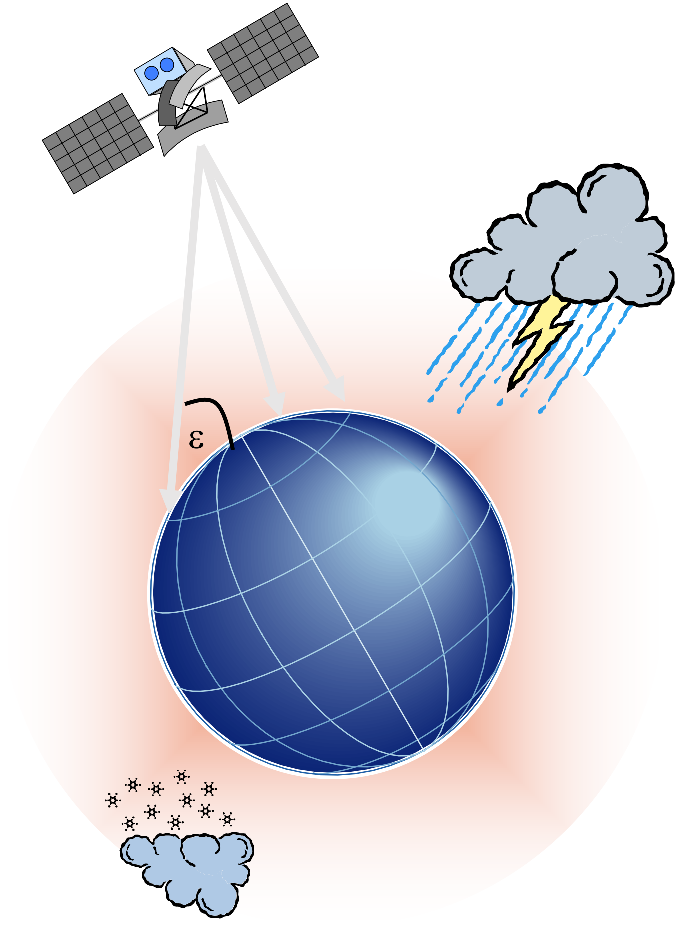
Basics

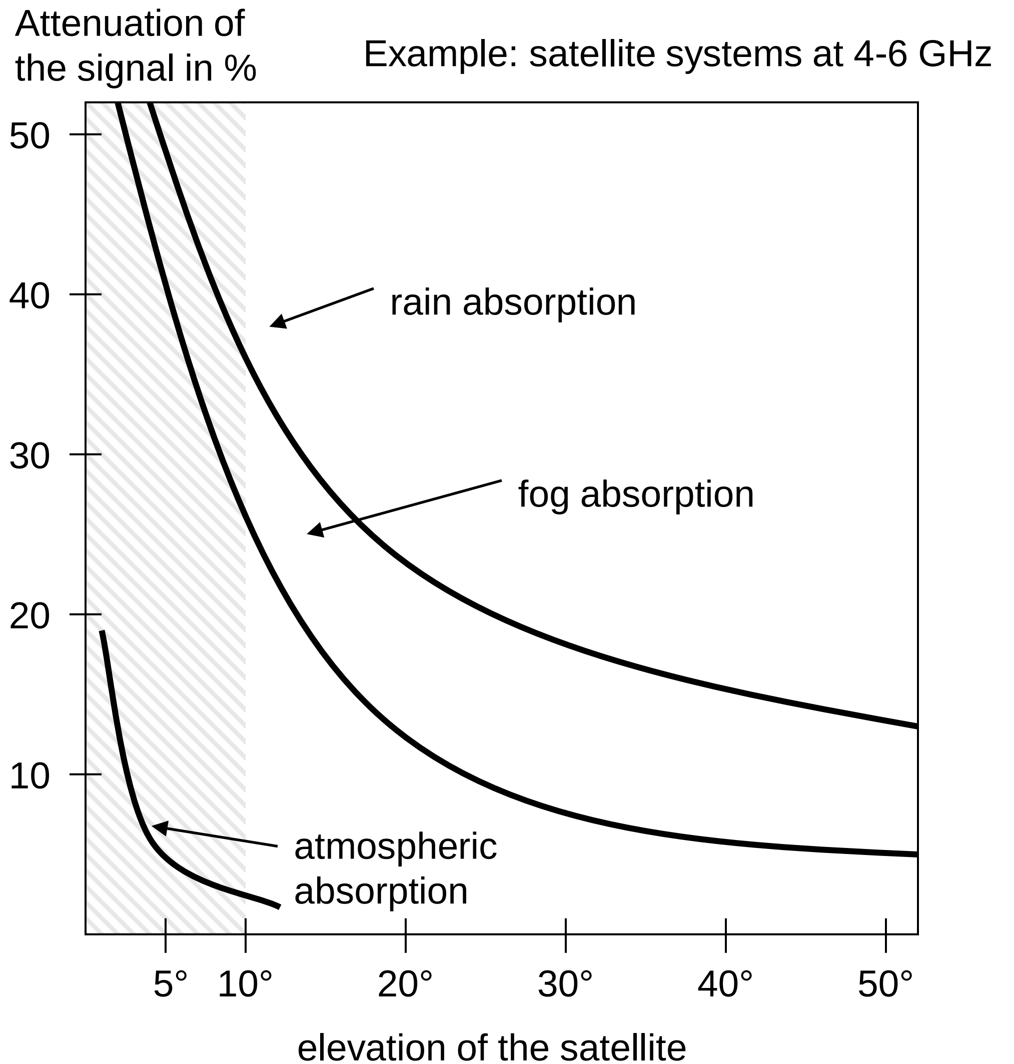
- elliptical or circular orbits
- complete rotation time depends on distance satellite-earth
- inclination: angle between orbit and equator
- elevation: angle between satellite and horizon
- LOS (Line of Sight) to the satellite necessary for connection
  ➔ high elevation needed, less absorption due to 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

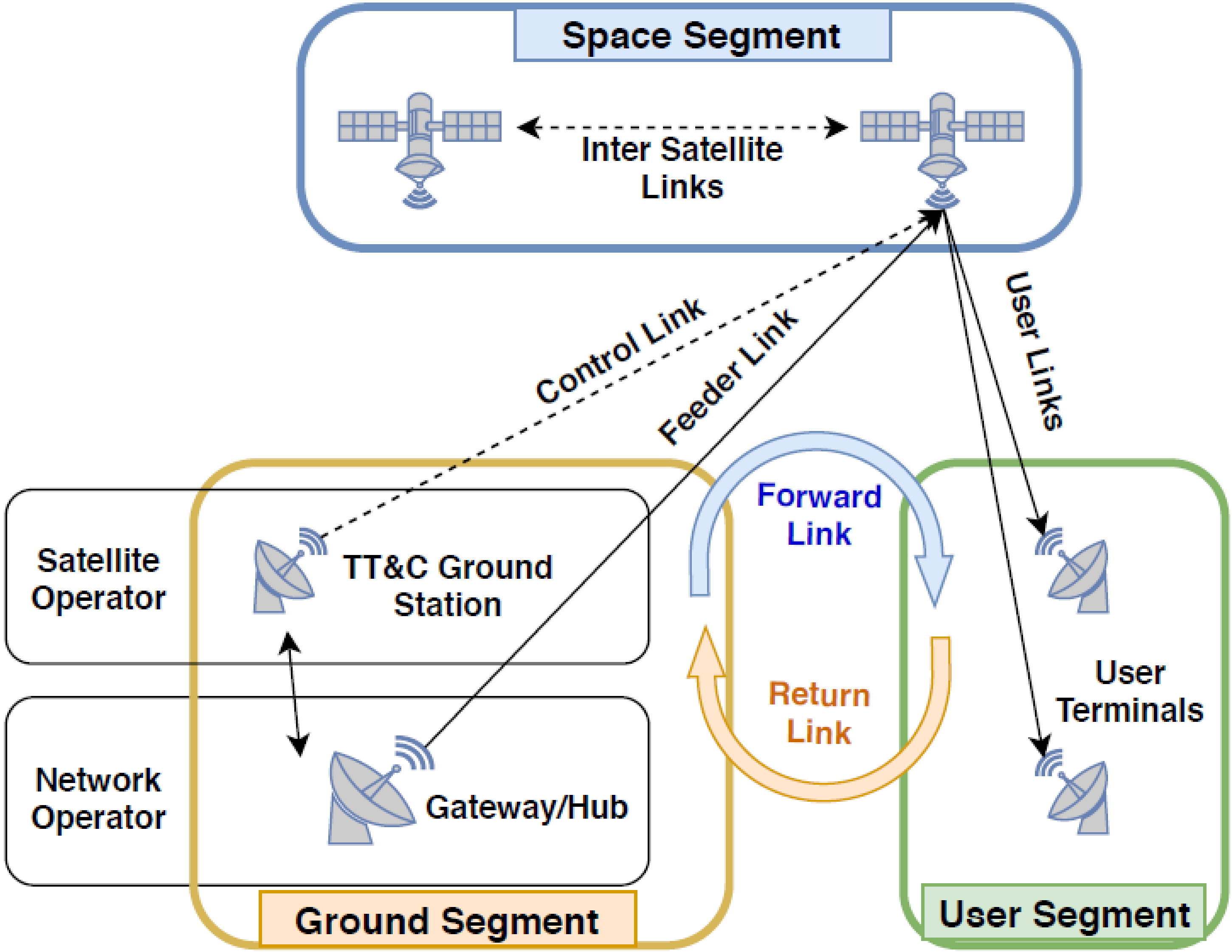
Features of Satellite Networks

- 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






Space Segment
Inter Satellite Links
Control Link
Feeder Link
User Links
Forward Link
Return Link
Satellite Operator
TT&C Ground Station
Network Operator
Gateway/Hub
User Terminals
Ground Segment
User Segment

Satellite Transmission Links

- Earth stations communicate by sending signals to the satellite on an uplink
- The satellite then repeats those signals on a downlink
- The broadcast nature of downlink makes it attractive for services such as the distribution of TV programs

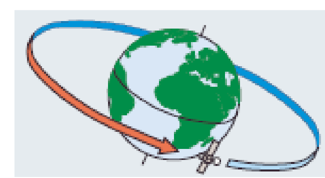
- Satellite up links and down links can operate in different frequency bands:

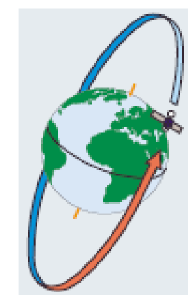
Band	Up-Link (Ghz)	Down-link (Ghz)	ISSUES
C	3,700-4,200 MHz	5,925-6,425 MHz	Interference with ground links.
Ku	11.7-12.2 GHz	14.0-14.5 GHz	Attenuation due to rain
Ka	17.7-21.2 GHz	27.5-31.0 GHz	High Equipment cost

- 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“.

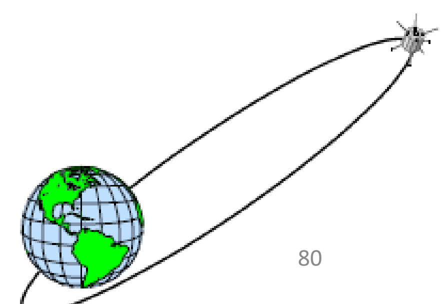
Types of Satellite Orbits

- 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 ($0°<i<90°$)



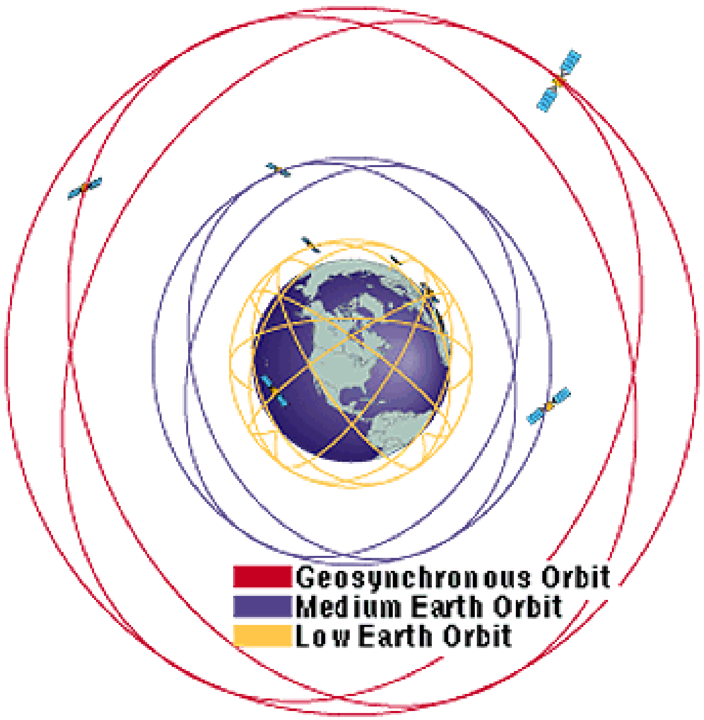


- Based on Eccentricity
  - Circular with centre at the earth’s centre
  - Elliptical with one foci at earth’s centre

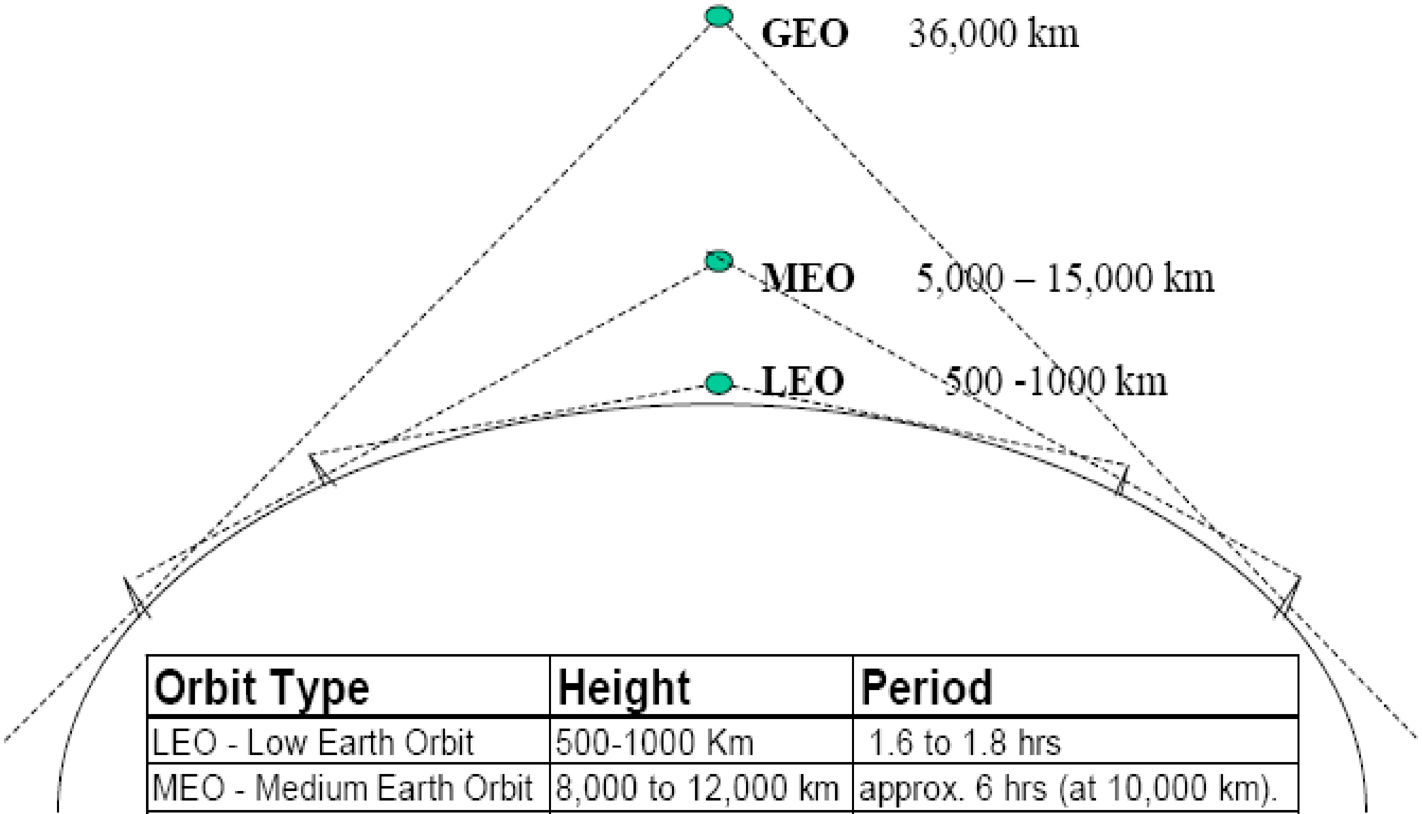


Types of Satellite based Networks

- 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



Satellite Orbits – Another perspective



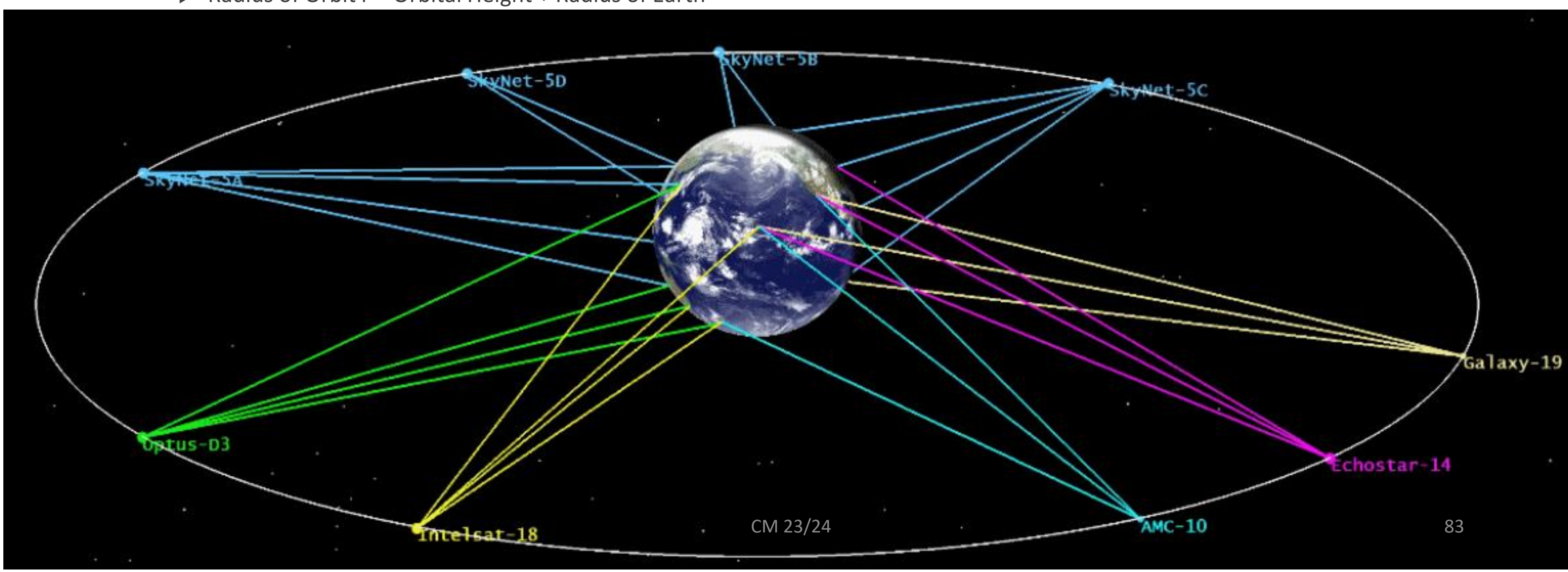
Orbit Type	Height	Period
LEO - Low Earth Orbit	500-1000 Km	1.6 to 1.8 hrs
MEO - Medium Earth Orbit	8,000 to 12,000 km	approx. 6 hrs (at 10,000 km).
GEO - Geostationary	approx. 36,870 km	approx. 24 hrs

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
  - Radius of Orbit r = Orbital Height + Radius of Earth



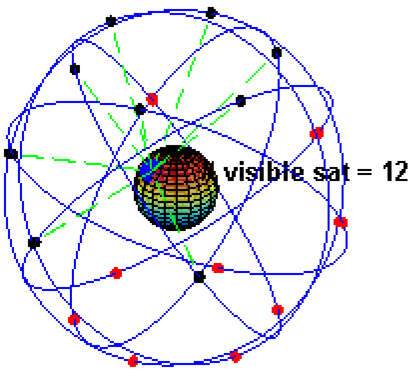
GEO Satellites

- 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

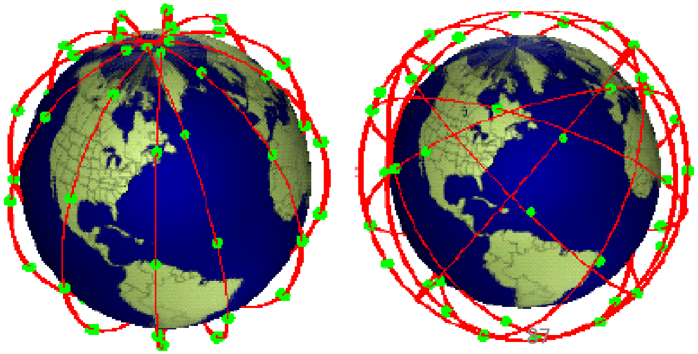
MEO Example: GPS



- 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 bet 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

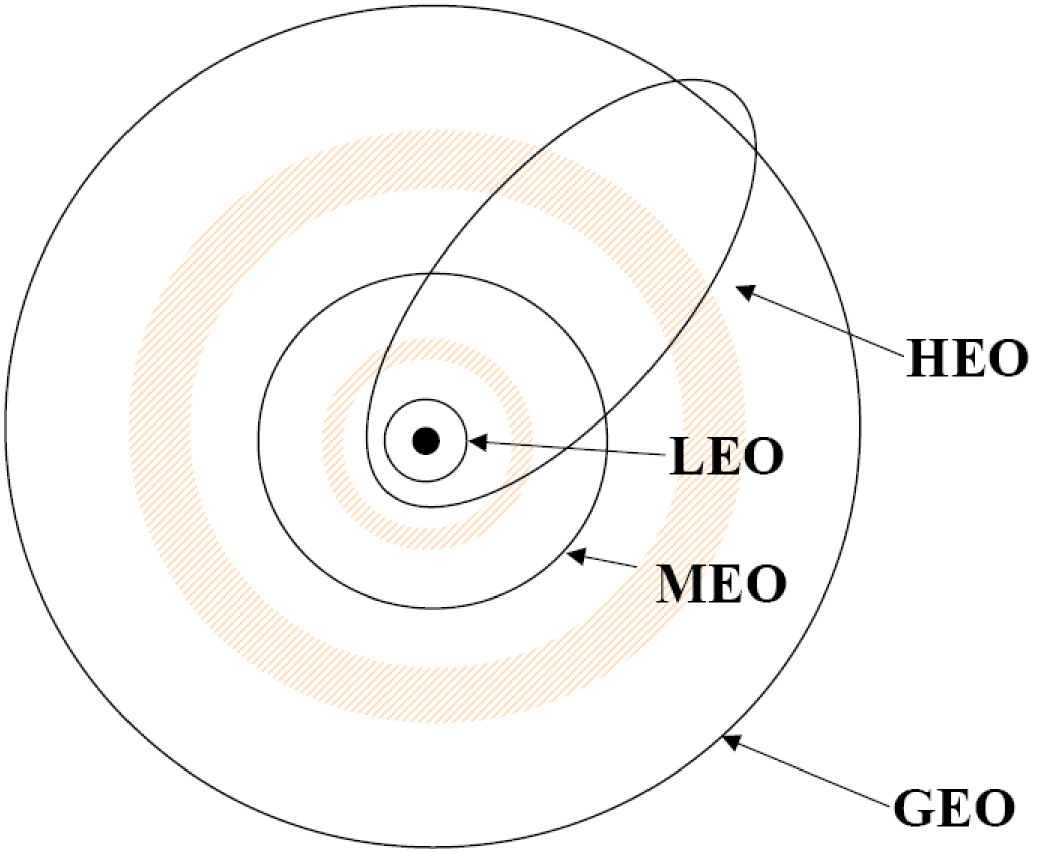


LEO Satellites

- 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

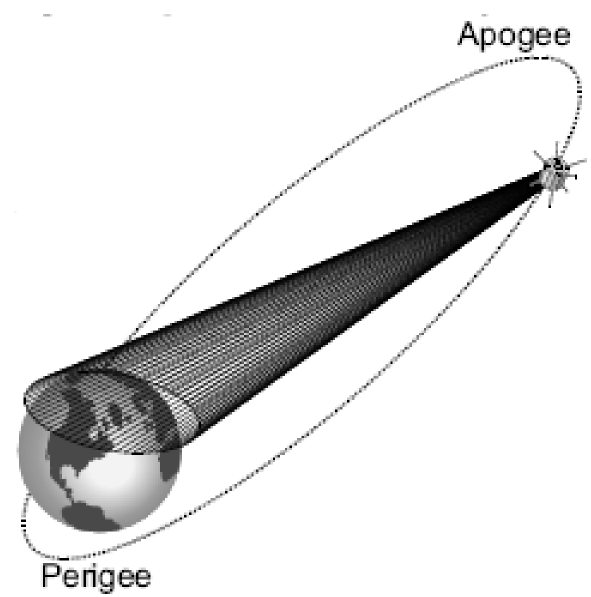
NGSO - Non Geostationary Orbits

- Orbit should avoid Van Allen radiation belts:
  - Region of charged particles that can cause damage to satellite
  - Occur at
    - ~2000-4000 km and
    - ~13000-25000 km



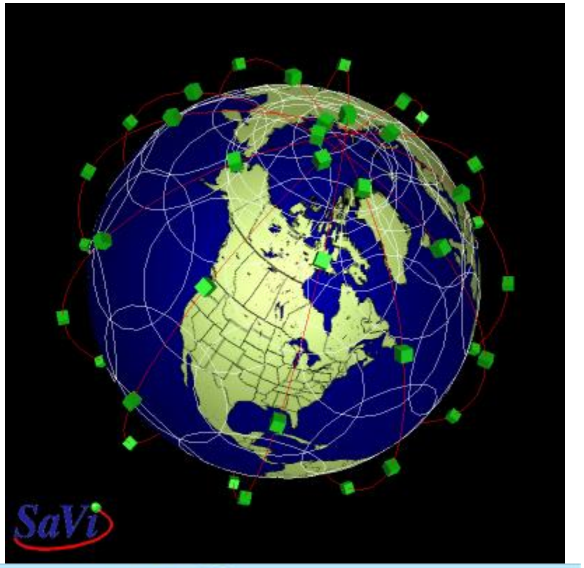
HEO - Highly Elliptical Orbits

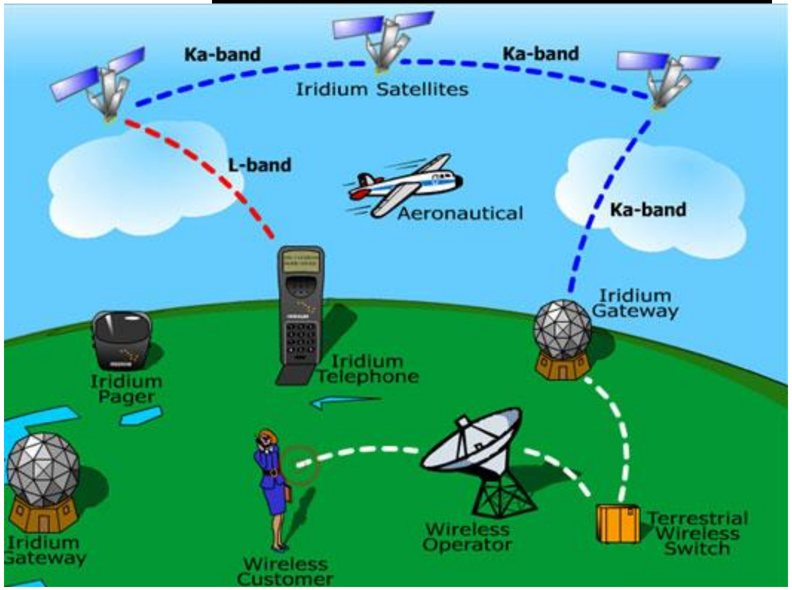
- HEOs (i = 63.4°) are suitable to provide coverage at high latitudes (including North Pole in the northern hemisphere)
- Depending on selected orbit (e.g. Molniya, Tundra, etc.) two or three satellites are sufficient for continuous time coverage of the service area.
- All traffic must be periodically transferred from the “setting” satellite to the “rising” satellite (Satellite Handover)



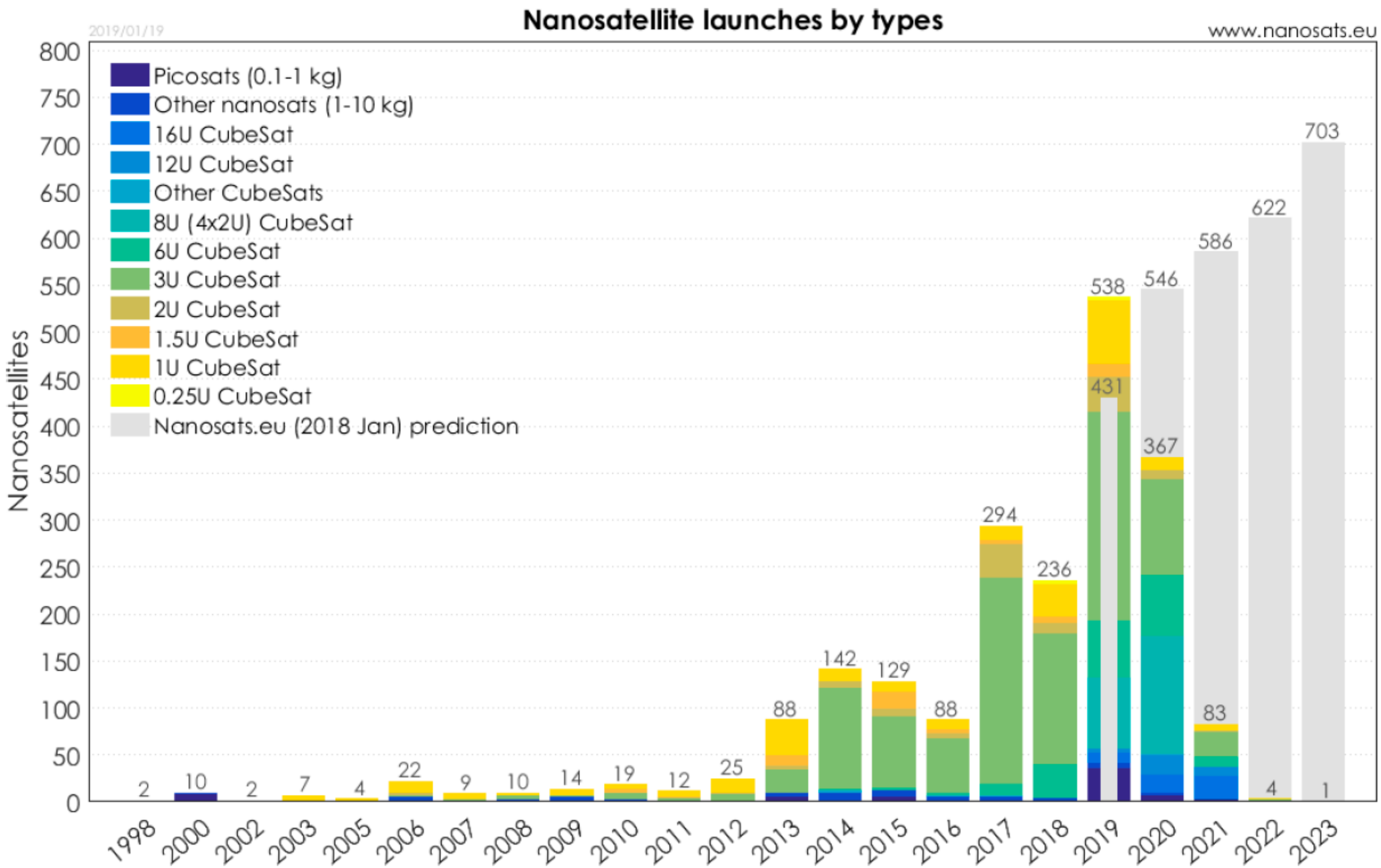
Iridium

- 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).

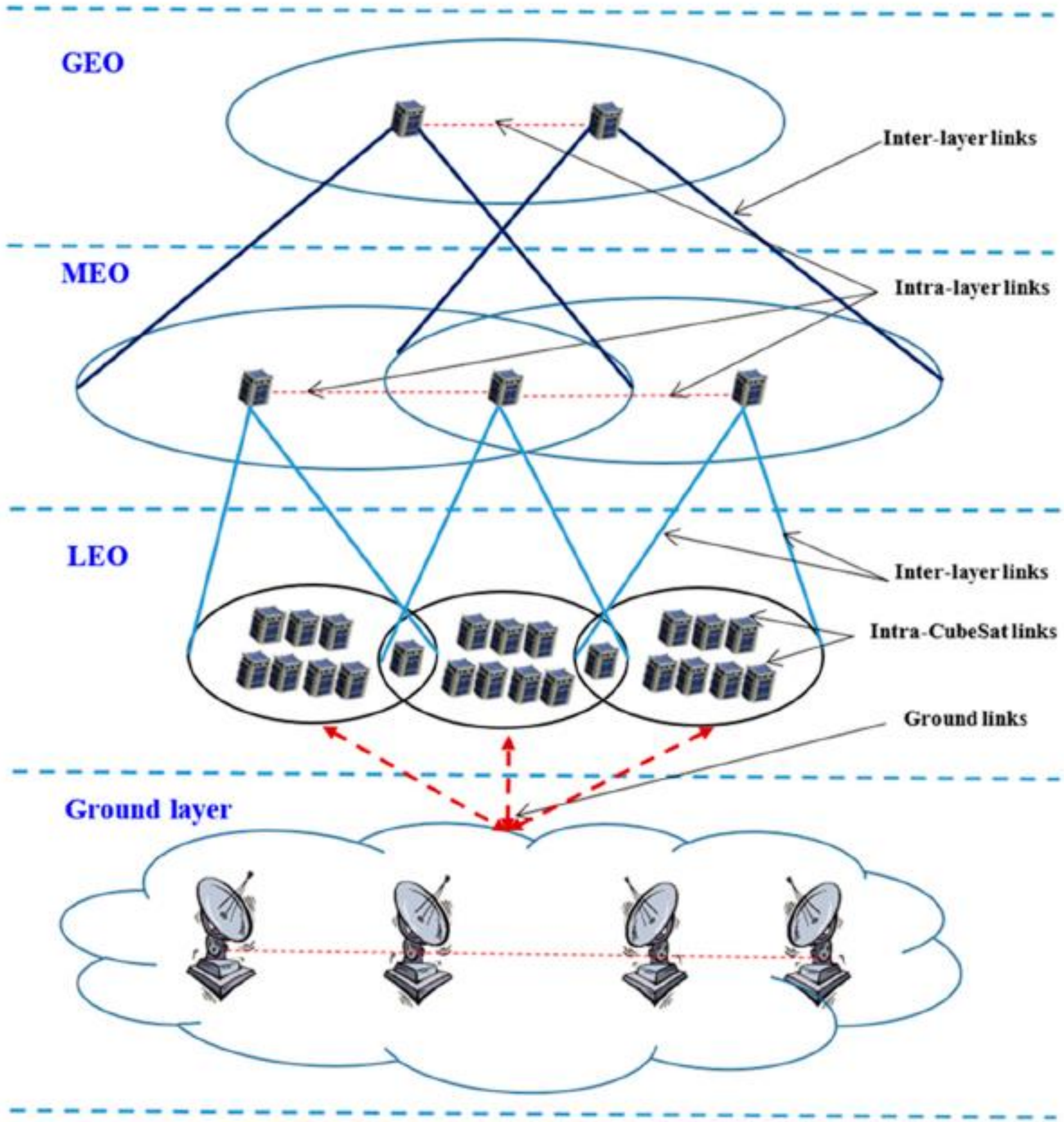




The cubesat explosion



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.

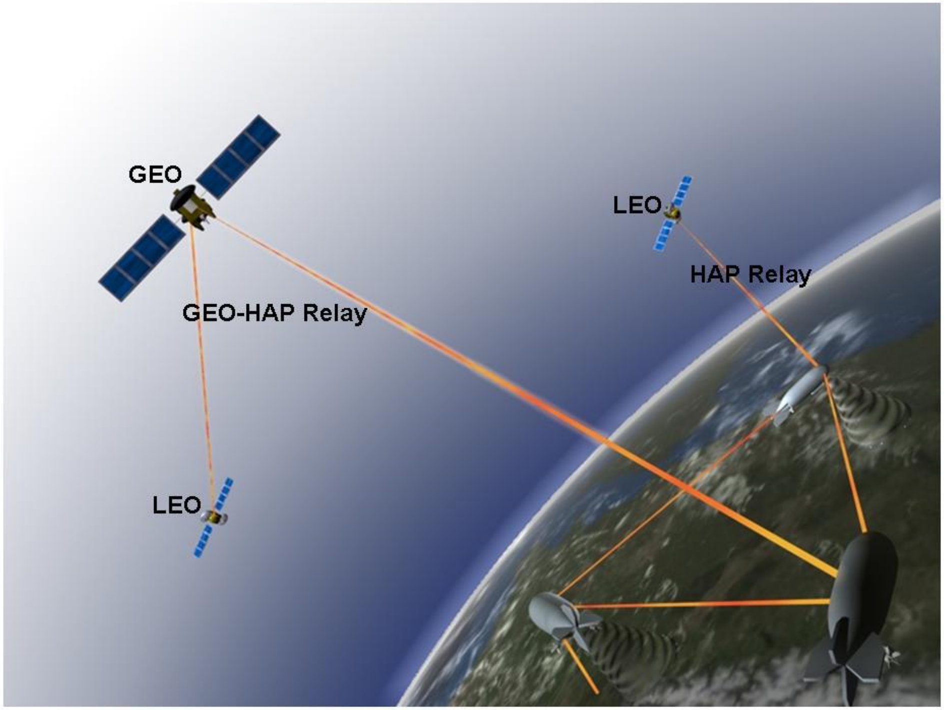


GEO
Inter-layer links
MEO
Intra-layer links
LEO
Inter-layer links
Intra-CubeSat links
Ground links
Ground layer

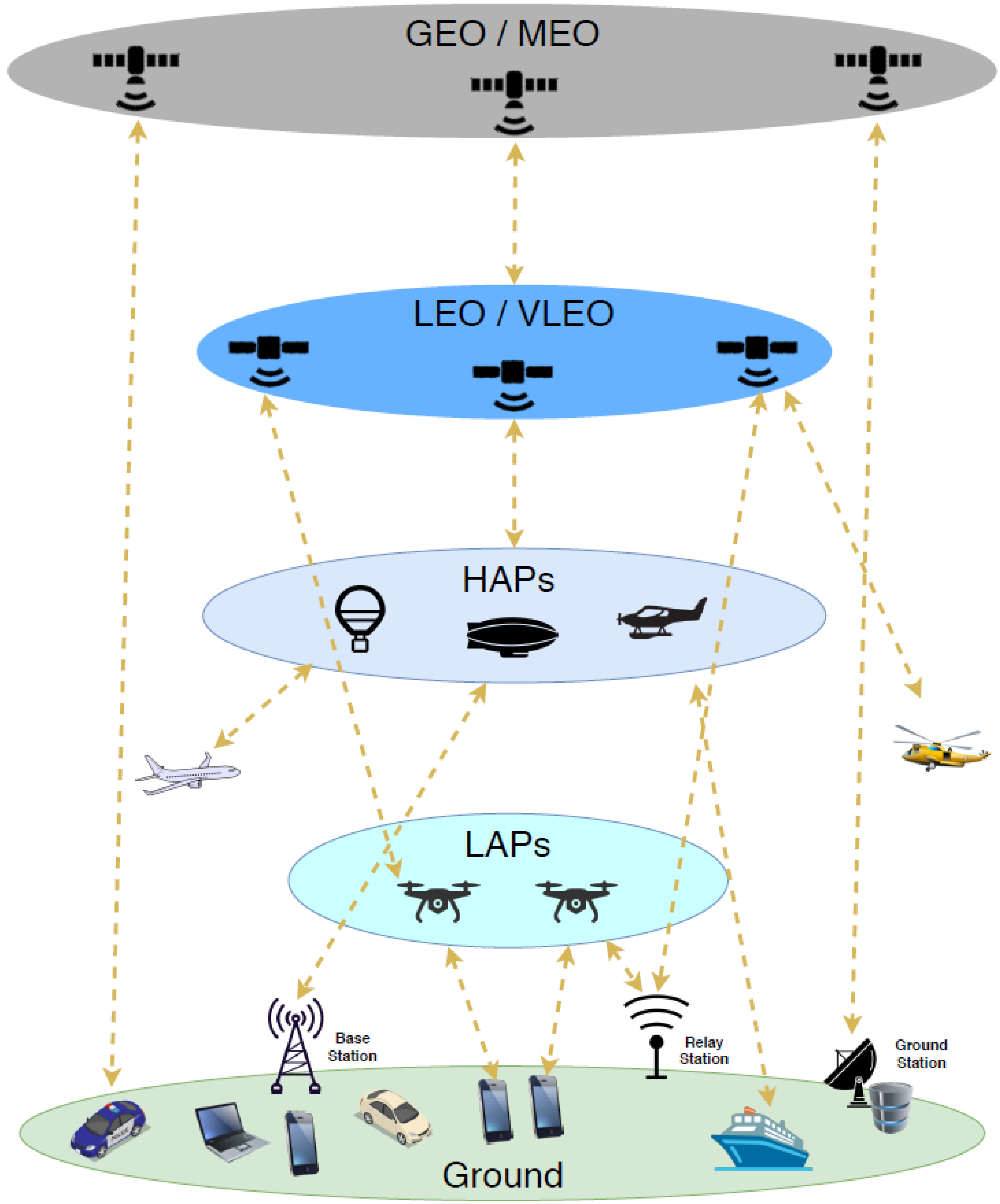
High Altitude Platforms (HAPs)

- 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.

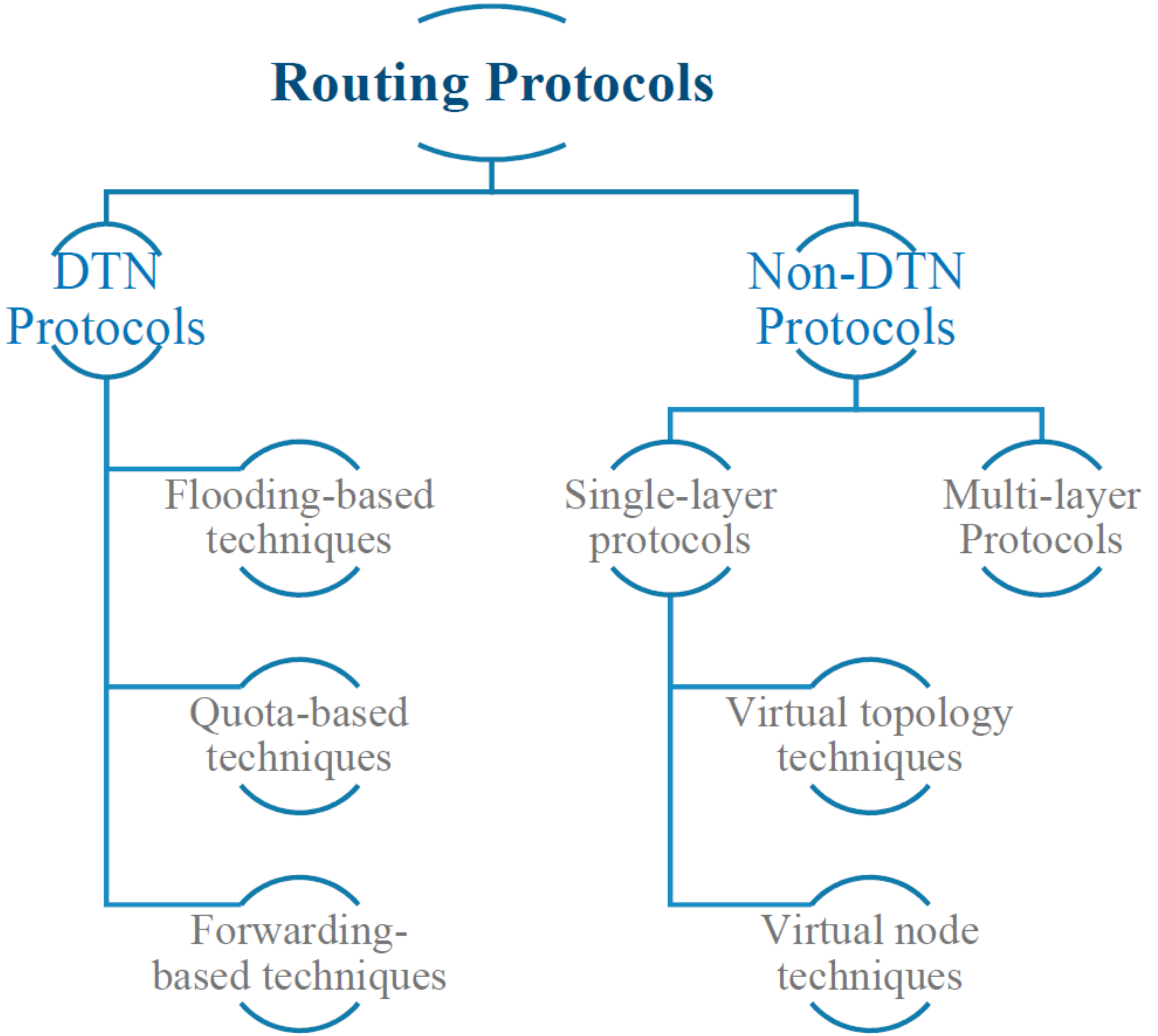

GEO / MEO
LEO / VLEO
HAPs
LAPs
Base Station
Relay Station
Ground Station
Ground

Satellites - Overview

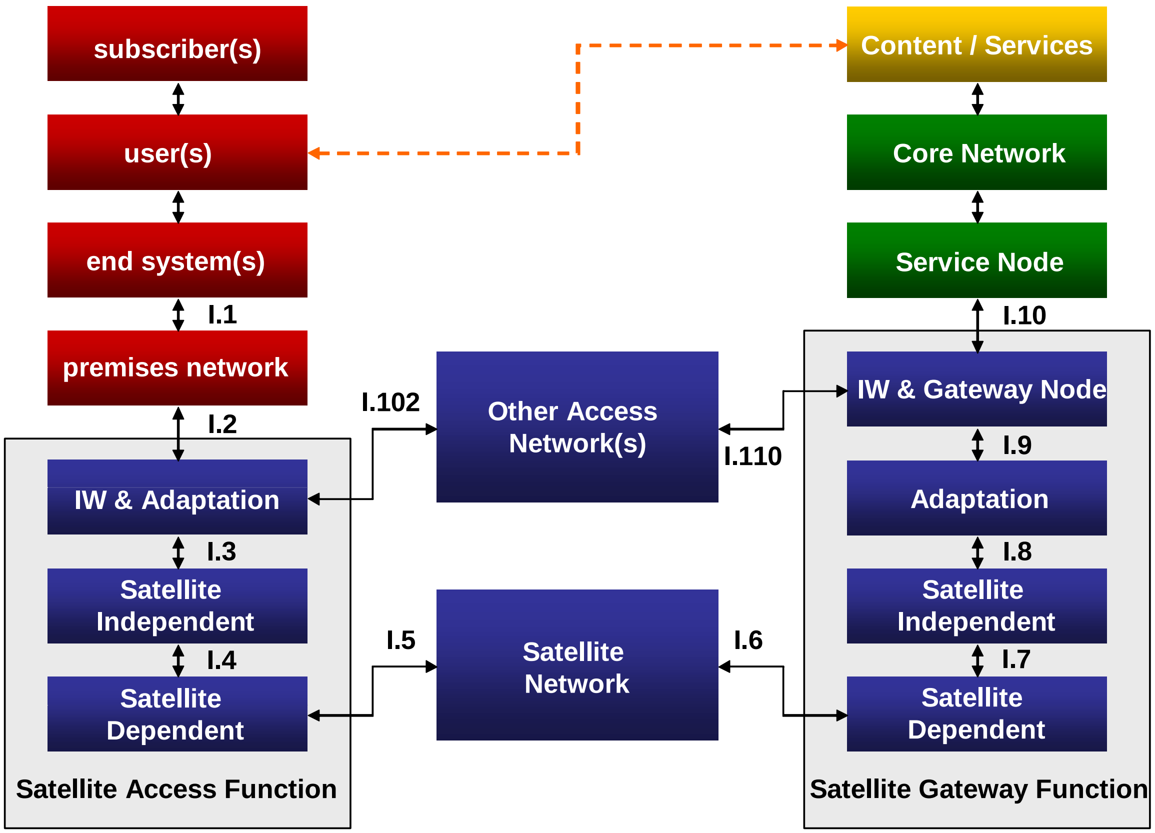
- GEOs have good broadcasting capability, but long propagation delay.
- LEOs offer low latency, low terminal power requirements.
- Inter-satellite links and on-board processing for increased performance and better utilization of satellites
  - From flying mirrors to intelligent routers on sky.
- Major 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

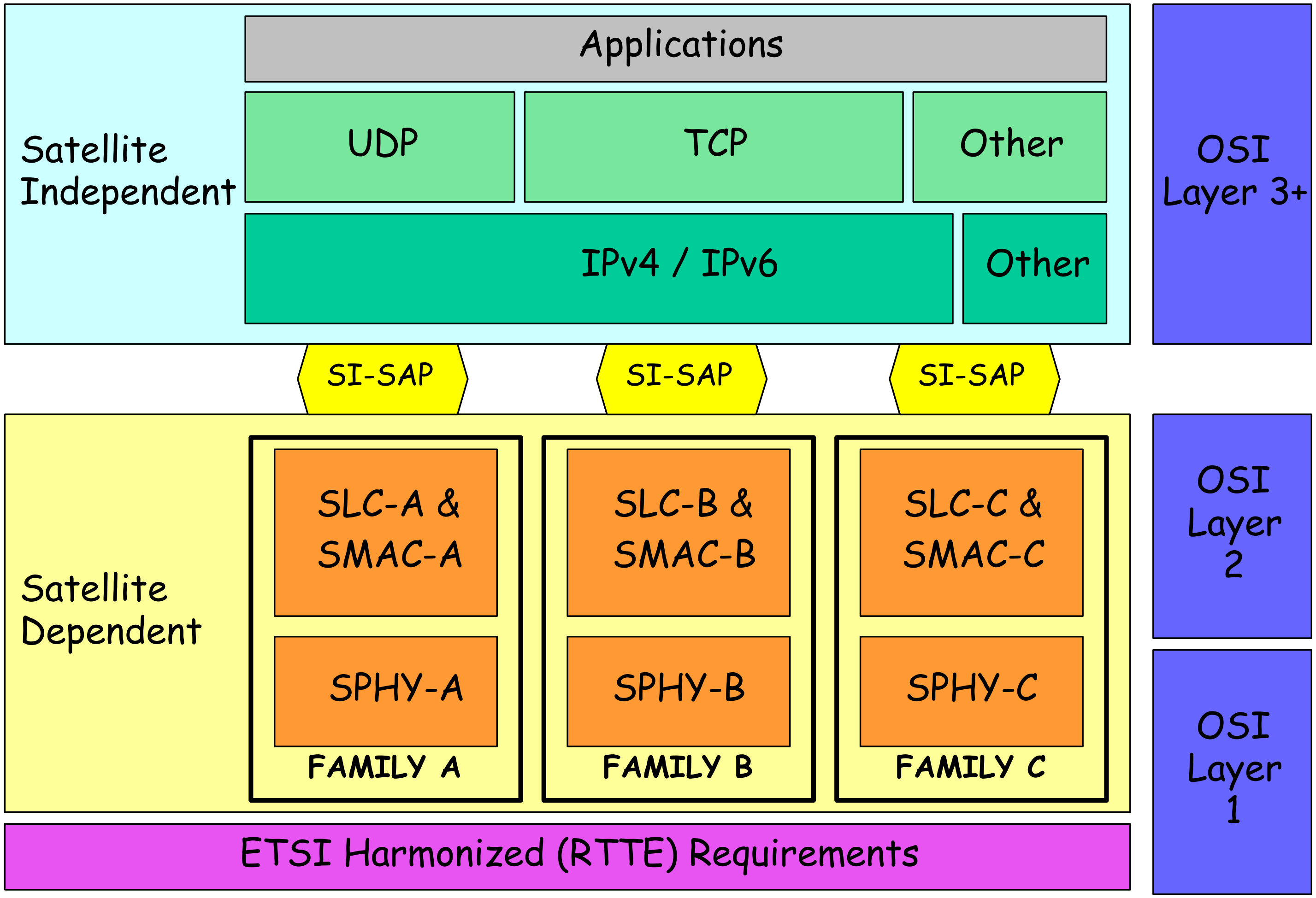
- One solution: inter satellite links (ISL)
  - reduced number of gateways needed
  - forward connections or data packets within the satellite network as long as possible
  - only one uplink and one downlink per direction needed for the connection of two mobile phones
- Problems:
  - more complex focusing 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


Routing Protocols
DTN Protocols
Non-DTN Protocols
Flooding-based techniques
Quota-based techniques
Forwarding-based techniques
Single-layer protocols
Multi-layer Protocols
Virtual topology techniques
Virtual node techniques

Reference model for satellite access

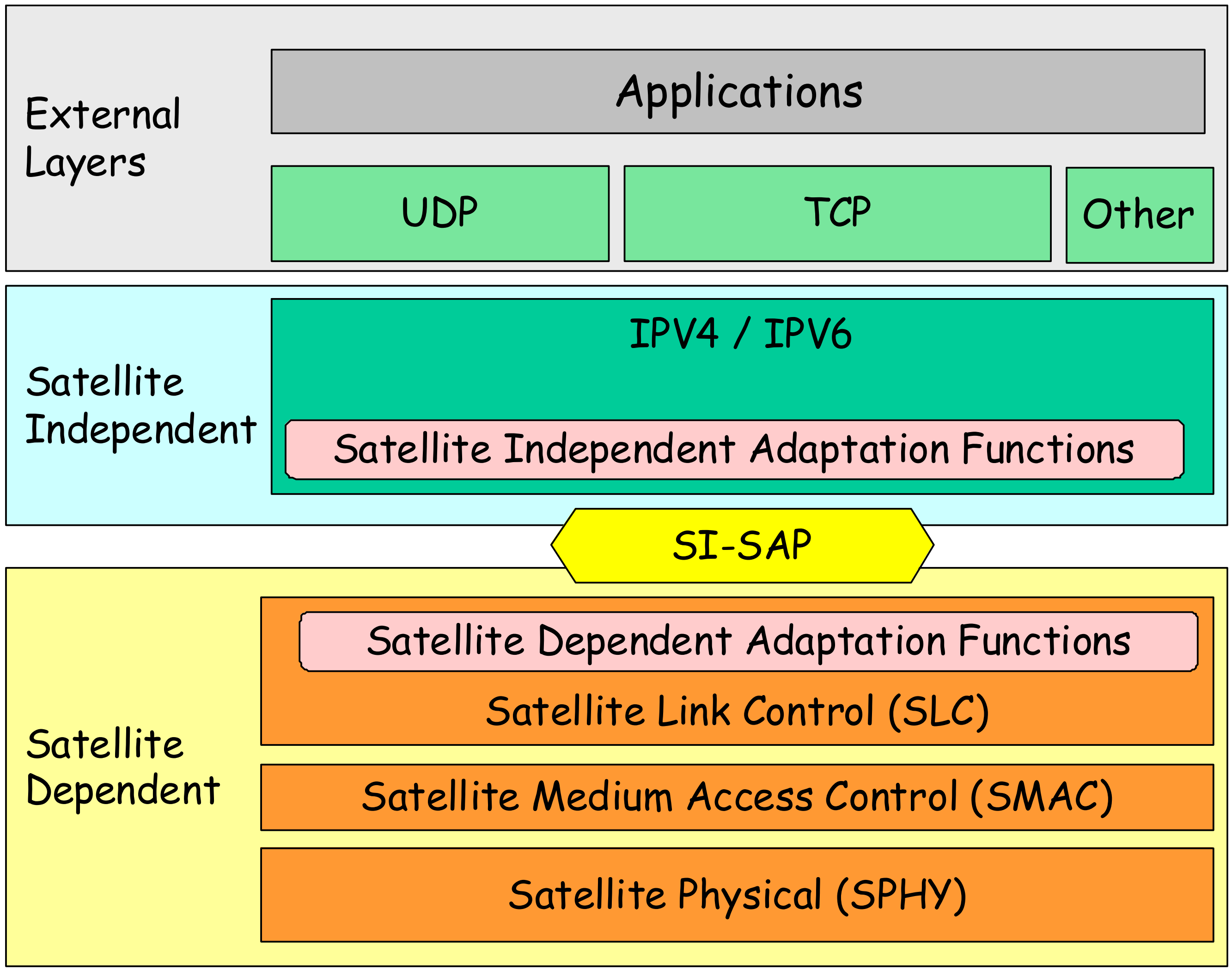


Protocol architecture



RTTE – Radio and Telecommunications Terminal Equipment Directive

Protocol architecture



IP interworking