5. Satellite Systems

History and Orbits
Routing, Localization, and Hand-over
Systems

History of Satellite Communications

- 1945 Arthur C. Clarke about "Extra Terrestrial Relays"
- 1957 First satellite SPUTNIK
- 1960 First reflecting communication satellite ECHO
- 1963 First geo-stationary satellite SYNCOM
- 1965 First commercial geo-stationary satellite "Early Bird"
  - INTELSAT I: 240 duplex telephone channels or 1 TV channel, 1.5 years lifetime
- 1976 Three MARISAT satellites (maritime communication)
- 1982 First mobile satellite telephone system INMARSAT-A
- 1988 First satellite system for mobile phones and data communication INMARSAT-C
- 1993 First digital satellite telephone system
- 1998 Global satellite systems for small mobile phones

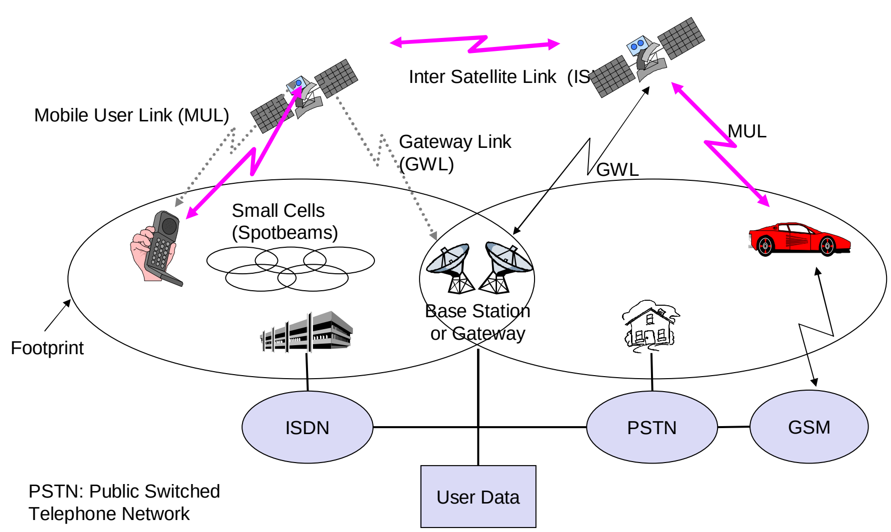
Applications

- Traditional:
  - Weather satellites
  - Radio and TV broadcast satellites
  - Military satellites
  - Satellites for navigation and localization (*e.g.*, GPS)

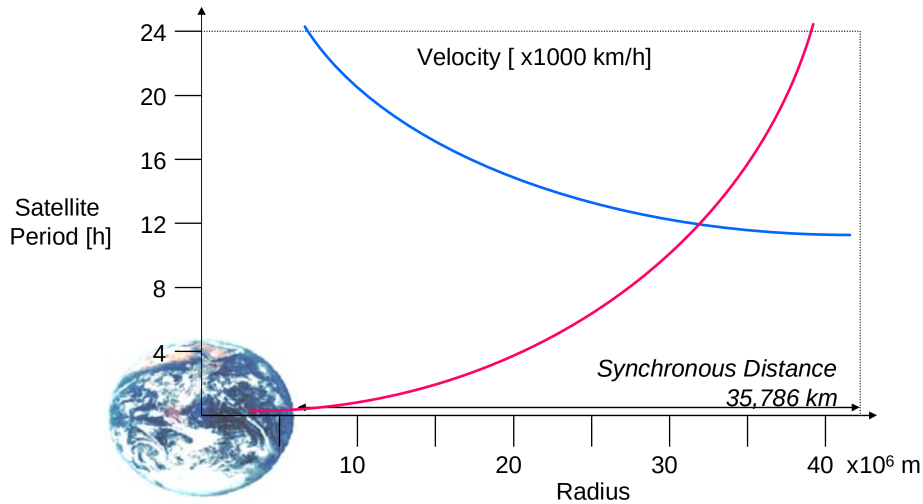
- Telecommunication:
  - Global telephone connections } replaced by fiber optics
  - Backbone for global networks } replaced by fiber optics
  - Connections for communication in remote places or underdeveloped areas
  - Global mobile communication

➔ Satellite systems extend cellular phone systems (*e.g.*, GSM or AMPS)

Classic Satellite Systems



Satellite Period and Orbits



Basics

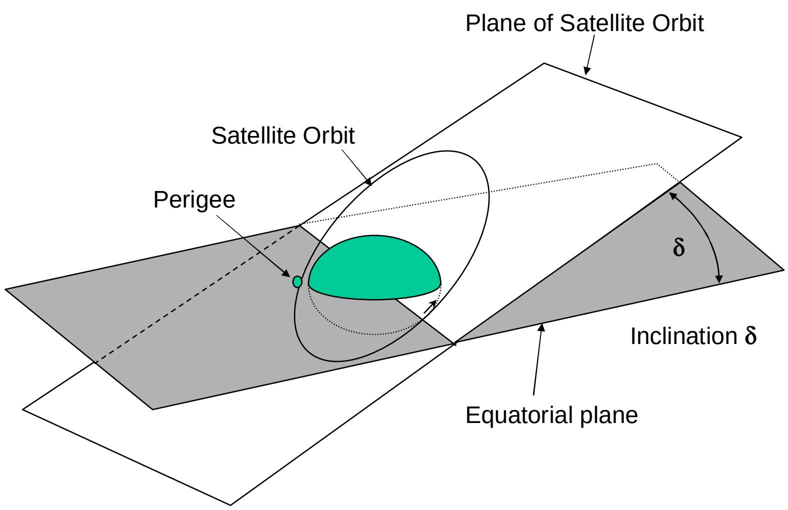
- Satellites in circular orbits:
  - Attractive force $F_g = m\ g\ (R/r)^2$
  - Centrifugal force $F_c = m\ r\ \omega^2$
  - m: mass of the satellite
  - R: radius of the earth (R = 6370 km)
  - r: distance to the center of the earth
  - g: acceleration of gravity (g = 9.81 m/s²)
  - ω: angular velocity ($\omega = 2\ \pi$ f, f: rotation frequency)
- Stable orbit:
  - $F_g = F_c$

$$r = \sqrt[3]{\frac{gR^2}{(2\pi f)^2}}$$

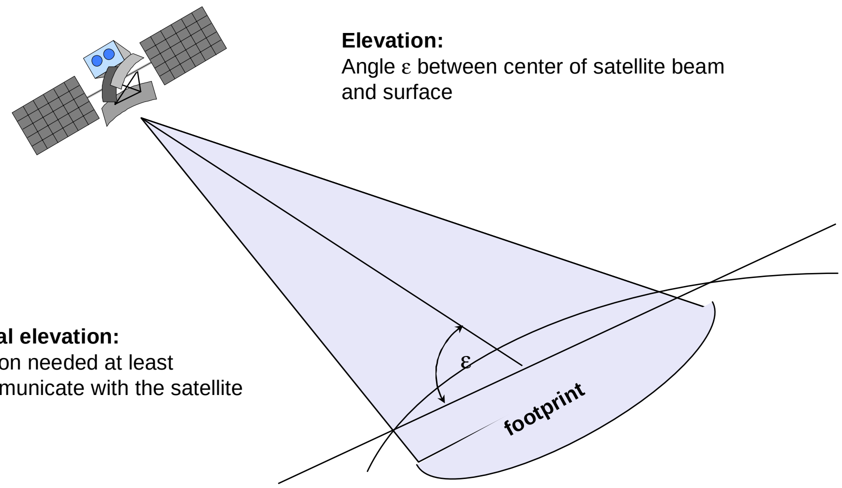
Terms and Definitions

- Elliptic 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
- Up-link: connection base station to satellite
- Down-link: connection satellite to base station
- Typically separated frequencies for up-link and down-link:
  - Transponder used for sending/receiving and shifting of frequencies
  - Transparent transponder: only shift of frequencies
  - regenerative transponder: additionally signal regeneration

Inclination



Elevation



Elevation:
Angle ε between center of satellite beam and surface

Minimal elevation:
Elevation needed at least to communicate with the satellite

Link Budget of Satellites

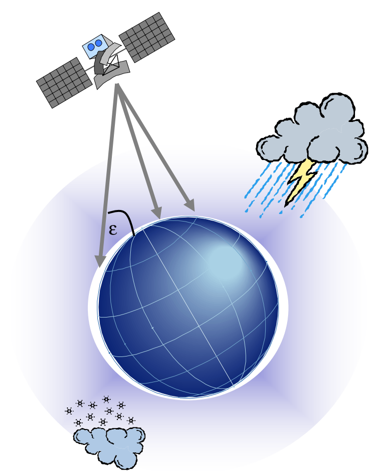
- Parameters like attenuation or received power determined by four parameters:
  - Sending power
  - Gain of sending antenna
  - Distance between sender and receiver
  - Gain of receiving antenna

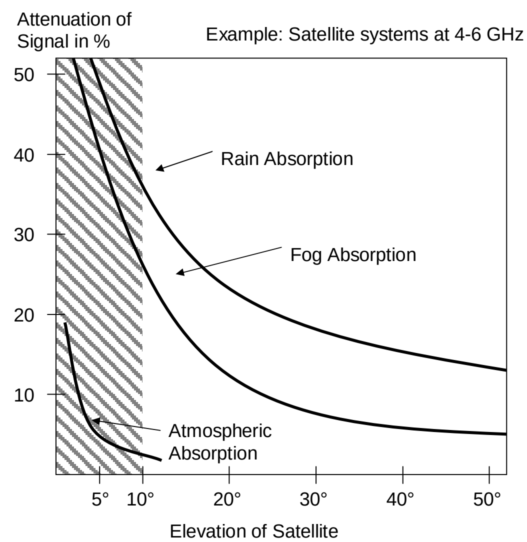
L: Loss
f: carrier frequency
r: distance
c: speed of light

$$L = \left(\frac{4 \pi r f}{c} \right)^2$$

- Problems:
  - Varying strength of received signal due to multi-path propagation
  - Interruptions due to shadowing of signal (no LOS)
- Possible solutions:
  - Link Margin to eliminate variations in signal strength
  - Satellite diversity (usage of several visible satellites at the same time) helps to use less sending power

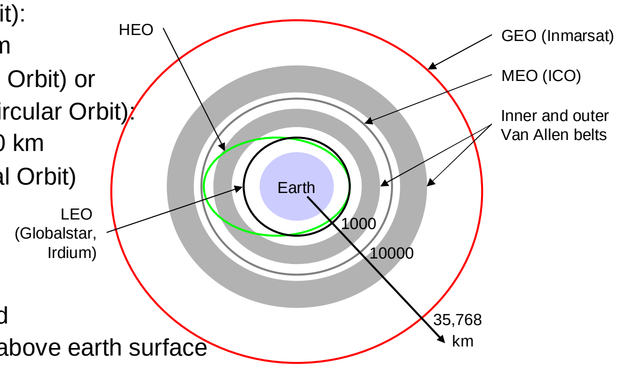
Atmospheric Attenuation





Orbits

- Four different types of satellite orbits identified depending on shape and diameter of orbit:
  - GEO: Geo-stationary orbit, about 36,000 km above earth surface
  - LEO (Low Earth Orbit): About 500 - 1,500 km
  - MEO (Medium Earth Orbit) or ICO (Intermediate Circular Orbit): About 6,000 - 20,000 km
  - HEO (Highly Elliptical Orbit) elliptical orbits
- Van-Allen-Belts:
  - Ionized particles at 2,000 - 6,000 km and 15,000 - 30,000 km above earth surface



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
- Examples:
  - Iridium and Teledesic planned with ISL
  - Other systems use gateways and additionally terrestrial networks

Localization of Mobile Stations

- Mechanisms similar to GSM
- Gateways maintain registers with user data:
  - HLR (Home Location Register):
    - Static user data
  - VLR (Visitor Location Register):
    - (Last known) location of the mobile station
  - SUMR (Satellite User Mapping Register):
    - Satellite assigned to a mobile station
    - Positions of all satellites
- Registration of mobile stations:
  - Localization of the mobile station via the satellite's position
  - Requesting user data from HLR and updating VLR and SUMR
- Calling a mobile station:
  - Localization using HLR/VLR similar to GSM
  - Connection setup using the appropriate satellite

Hand-over in Satellite Systems

- Additional situations for hand-over in satellite systems compared to cellular terrestrial mobile phone networks caused by the movement of the satellites
  - Intra-satellite hand-over
    - Hand-over from one spot beam to another
    - Mobile station still in the footprint of the satellite, but in another cell
  - Inter-satellite hand-over
    - Hand-over from one satellite to another satellite
    - Mobile station leaves the footprint of one satellite
  - Gateway hand-over
    - Hand-over from one gateway to another
    - Mobile station still in the footprint of a satellite, but gateway leaves footprint
  - Inter-system hand-over
    - Hand-over from the satellite network to a terrestrial cellular network
    - Mobile station can reach a terrestrial network again which might be cheaper, has a lower latency

Geo-stationary Satellites

- Orbit 35,786 km distance to earth surface, orbit in equatorial plane (inclination 0°)
  - Complete rotation exactly one day, satellite is synchronous to earth rotation
  - Fixed antenna positions, no adjusting necessary
  - Satellites typically have a large footprint (up to 34% of earth surface!), therefore, difficult to reuse frequencies
  - Bad elevations in areas with latitude above 60° due to fixed position above the equator
  - High transmission power needed
  - High latency due to long distance (about 275 ms)

- Not useful for global coverage for small mobile phones and data transmission
- Typically used for radio and TV transmission

LEO Systems

- Orbit about 500 - 1,500 km above earth surface
- Visibility of a satellite about 10 - 40 minutes
- Global radio coverage possible
- Latency comparable with terrestrial long distance connections, ca. 5 - 10 ms
- Smaller footprints, better frequency reuse
- But now handover necessary from one satellite to another
- Many satellites necessary for global coverage
- More complex systems due to moving satellites
- Examples:
  - Iridium (start 1998, 66 satellites):
    - Bankruptcy in 2000, deal with US DoD (free use, saving from "de-orbiting")
  - Globalstar (start 1999, 48 satellites):
    - Not many customers (2001: 44000), low stand-by times for mobiles

MEO Systems

- Orbit about 5,000 - 12,000 km above earth surface
- Comparison with LEO systems:
  - Slower moving satellites
  - Less satellites needed
  - Simpler system design
  - For many connections no hand-over needed
  - Higher latency, ca. 70 - 80 ms
  - Higher sending power needed
  - Special antennas for small footprints needed
- Examples:
  - ICO (Intermediate Circular Orbit, Inmarsat) start about 2000
    - Bankruptcy, but planning for IP traffic
    - Planned joint ventures with Teledesic, Ellipso – cancelled again, initial components planned for 2003, full new start planned for 2005

Overview of LEO/MEO Systems

	Iridium	Globalstar	ICO	Teledesic
# Satellites	66 + 6	48 + 4	10 + 2	288
Altitude (km)	780	1414	10390	ca. 700
Coverage	global	±70° latitude	global	global
Min. Elevation	8°	20°	20°	40°
Frequencies [GHz (about)]	1.6 MS 29.2 ↑ 19.5 ↓ 23.3 ISL	1.6 MS ↑ 2.5 MS ↓ 5.1 ↑ 6.9 ↓	2 MS ↑ 2.2 MS ↓ 5.2 ↑ 7 ↓	19 ↓ 28.8 ↑ 62 ISL
Access Method	FDMA/TDMA	CDMA	FDMA/TDMA	FDMA/TDMA
ISL	yes	no	no	yes
Bit Rate	2.4 kbit/s	9.6 kbit/s	4.8 kbit/s	64 Mbit/s ↓ 2/64 Mbit/s ↑
# Channels	4000	2700	4500	2500
Lifetime [years]	5-8	7.5	12	10
Cost Estimation	4.4 B$	2.9 B$	4.5 B$	9 B$