Mobile Communications
Chapter 5: Satellite Systems

- ❑ History
- ❑ Basics
- ❑ Localization
- ❑ Handover
- ❑ Routing
- ❑ Systems

History of satellite communication

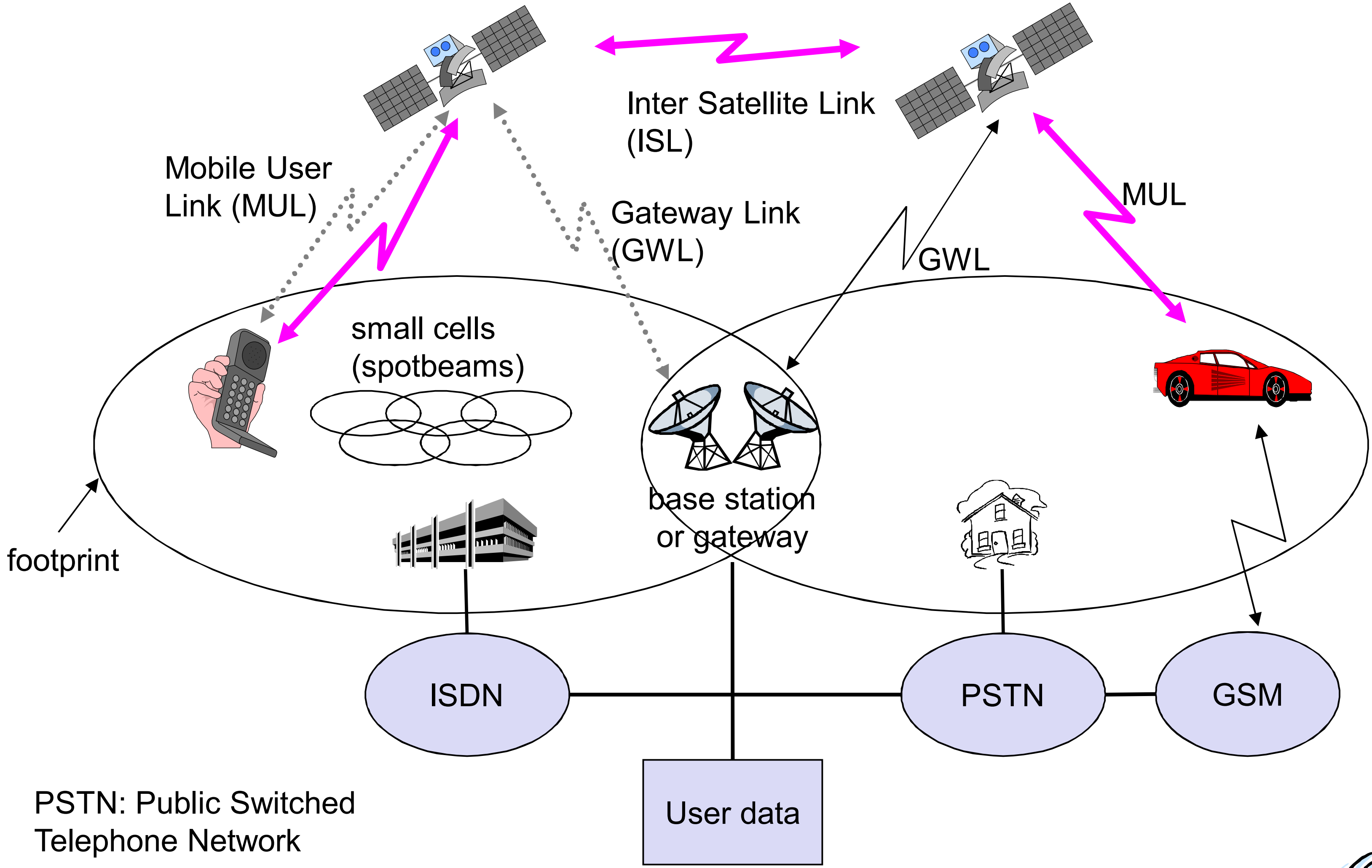
1945	Arthur C. Clarke publishes an essay about „Extra Terrestrial Relays“
1957	first satellite SPUTNIK
1960	first reflecting communication satellite ECHO
1963	first geostationary satellite SYNCOM
1965	first commercial geostationary satellite Satellit „Early Bird“ (INTELSAT I): 240 duplex telephone channels or 1 TV channel, 1.5 years lifetime
1976	three MARISAT satellites for 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

- Traditionally
  - 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 to extend cellular phone systems (e.g., GSM or AMPS)

Classical satellite systems



PSTN: Public Switched
Telephone Network

Basics

Satellites in circular orbits

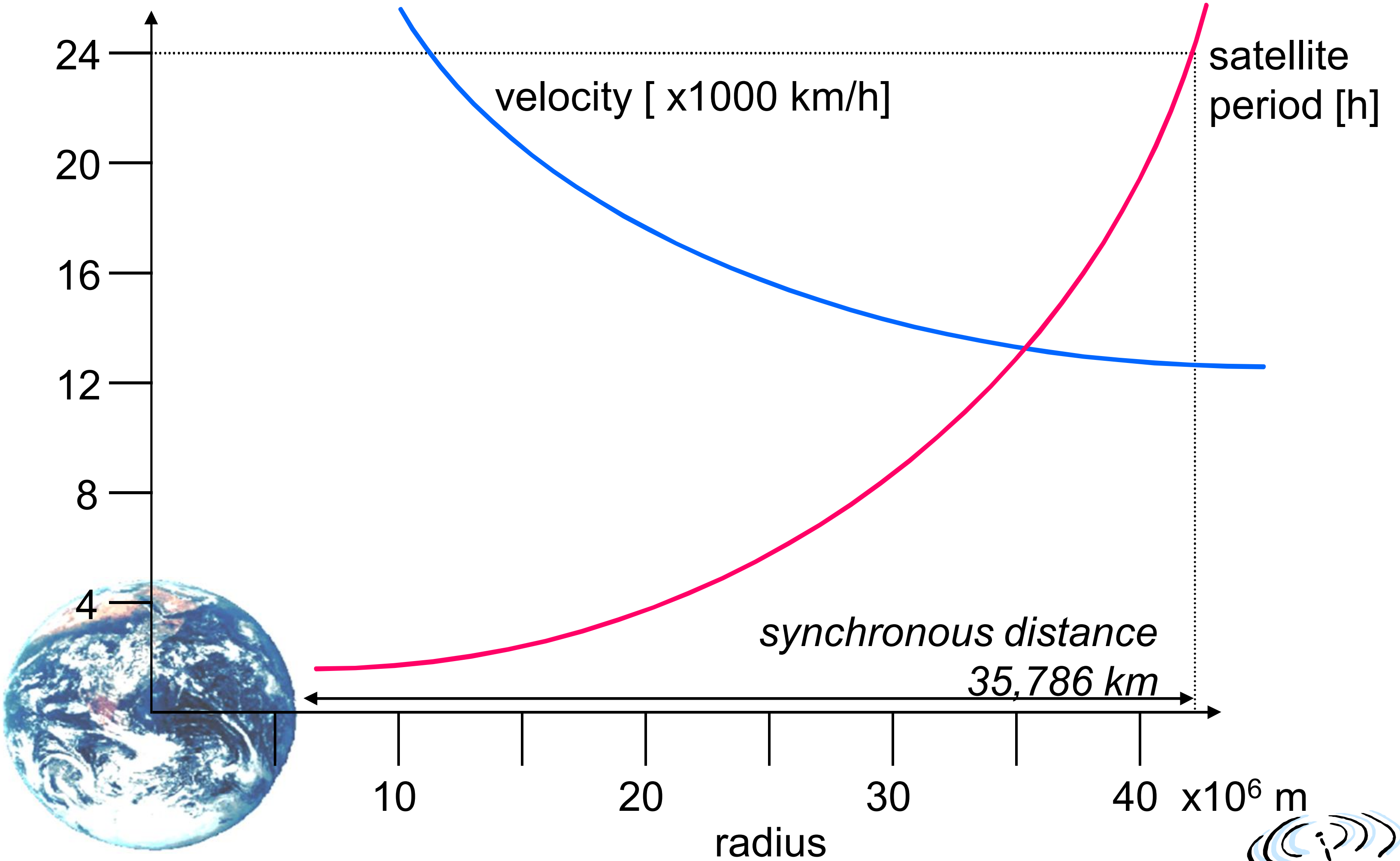
- attractive force $F_g = m\, g\, (R/r)^2$
- centrifugal force $F_c = m\, r\, \omega^2$
- m: mass of the satellite
- R: radius of the earth (R = 6370 km)
- r: distance to the center of the earth
- g: acceleration of gravity (g = 9.81 m/s²)
- ω: angular velocity ($\omega = 2\, \pi\, f$, f: rotation frequency)

Stable orbit

- $F_g = F_c$

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

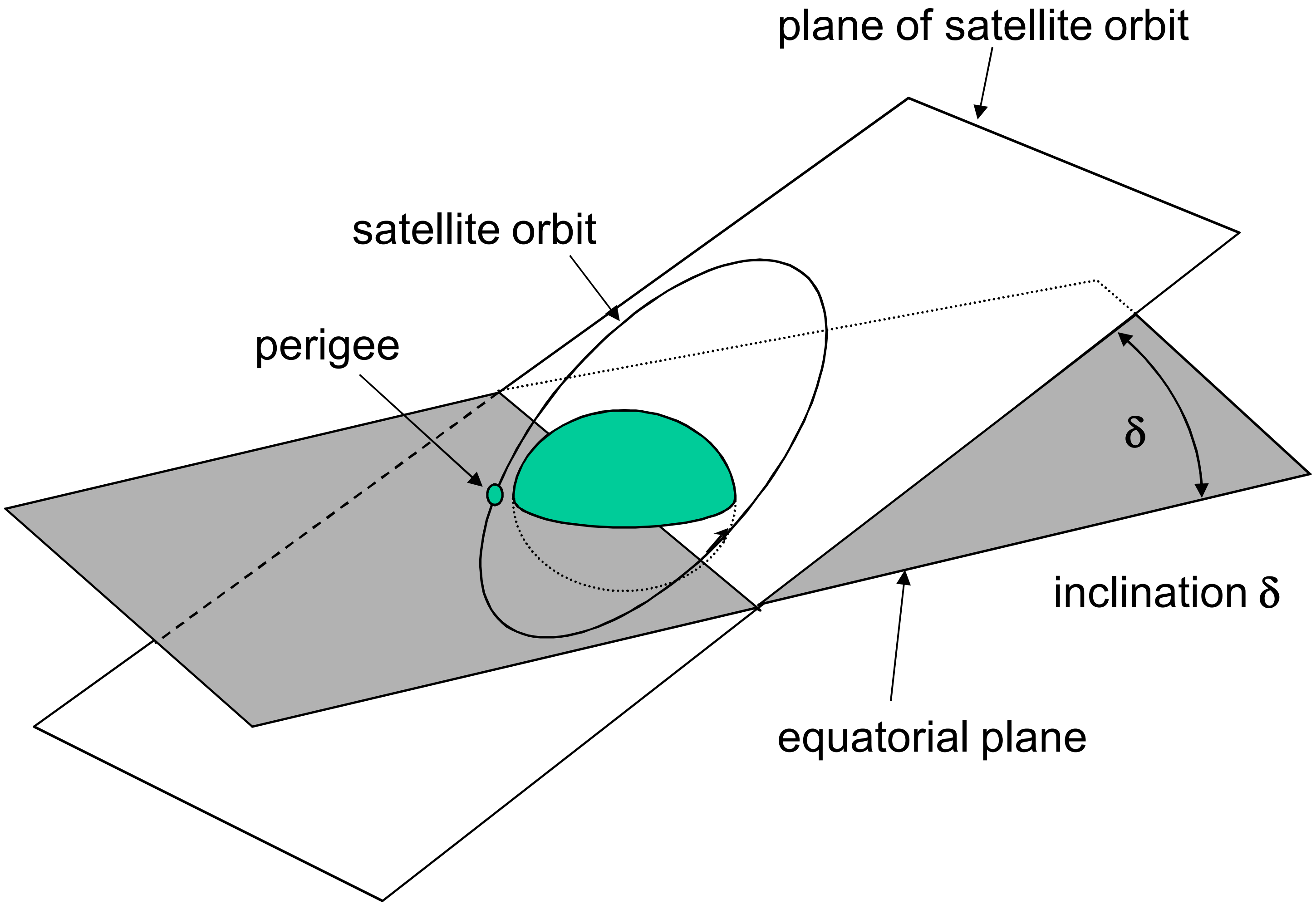
Satellite period and orbits



Basics

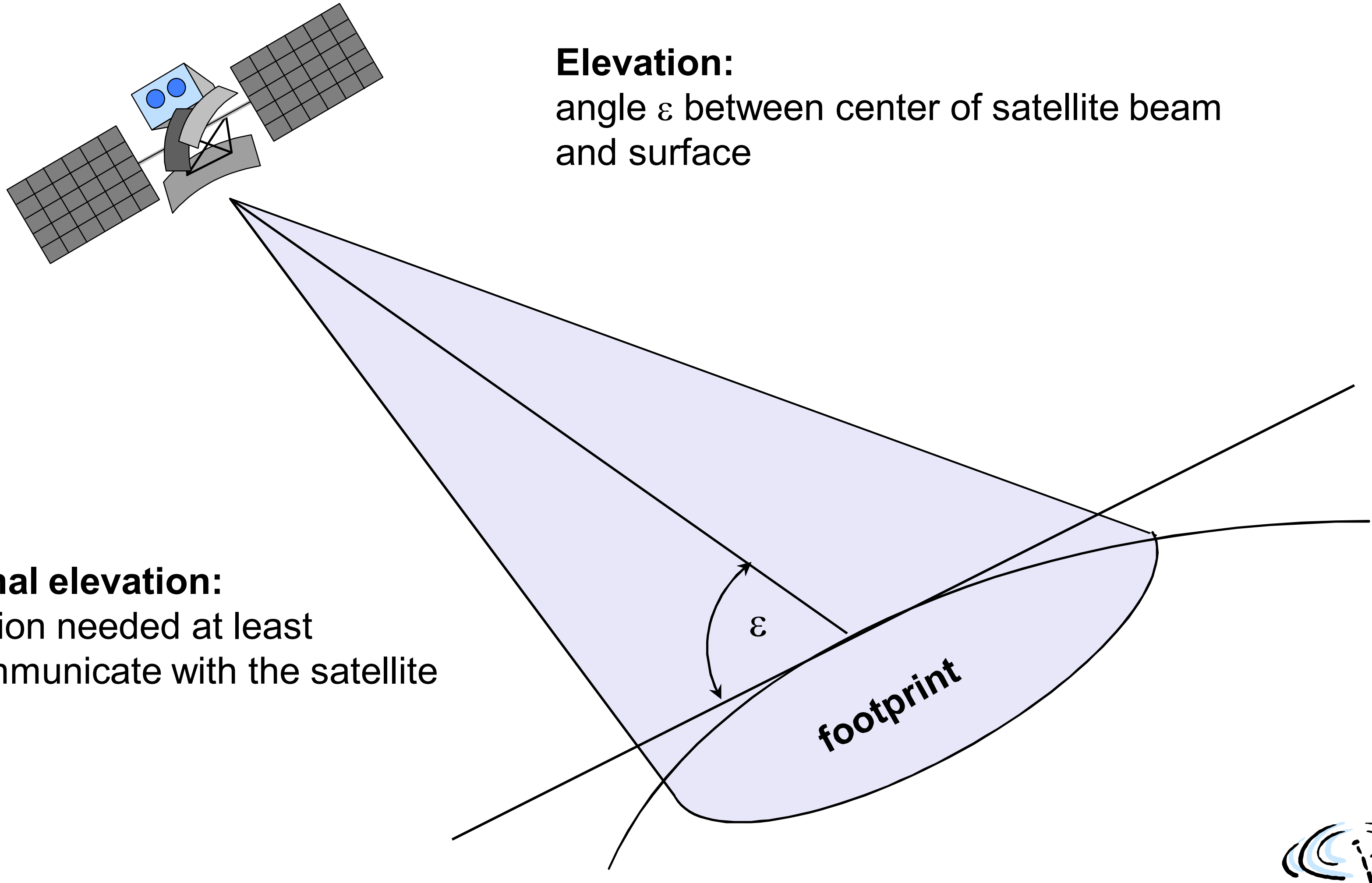
- elliptical or circular orbits
- complete rotation time depends on distance satellite-earth
- inclination: angle between orbit and equator
- elevation: angle between satellite and horizon
- LOS (Line of Sight) to the satellite necessary for connection
  - ➔ high elevation needed, less absorption due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

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

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

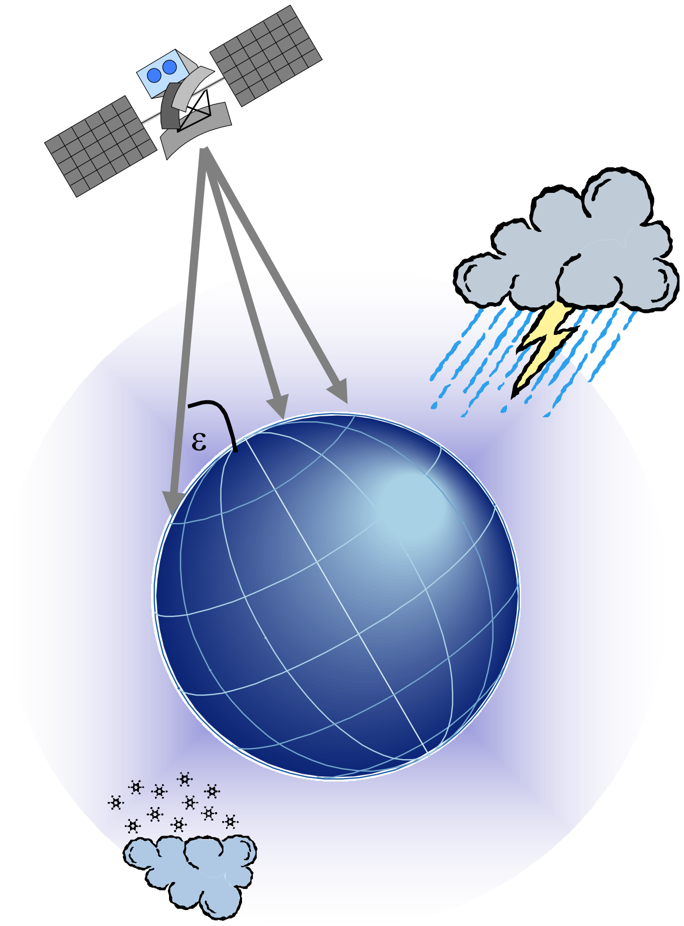
Problems

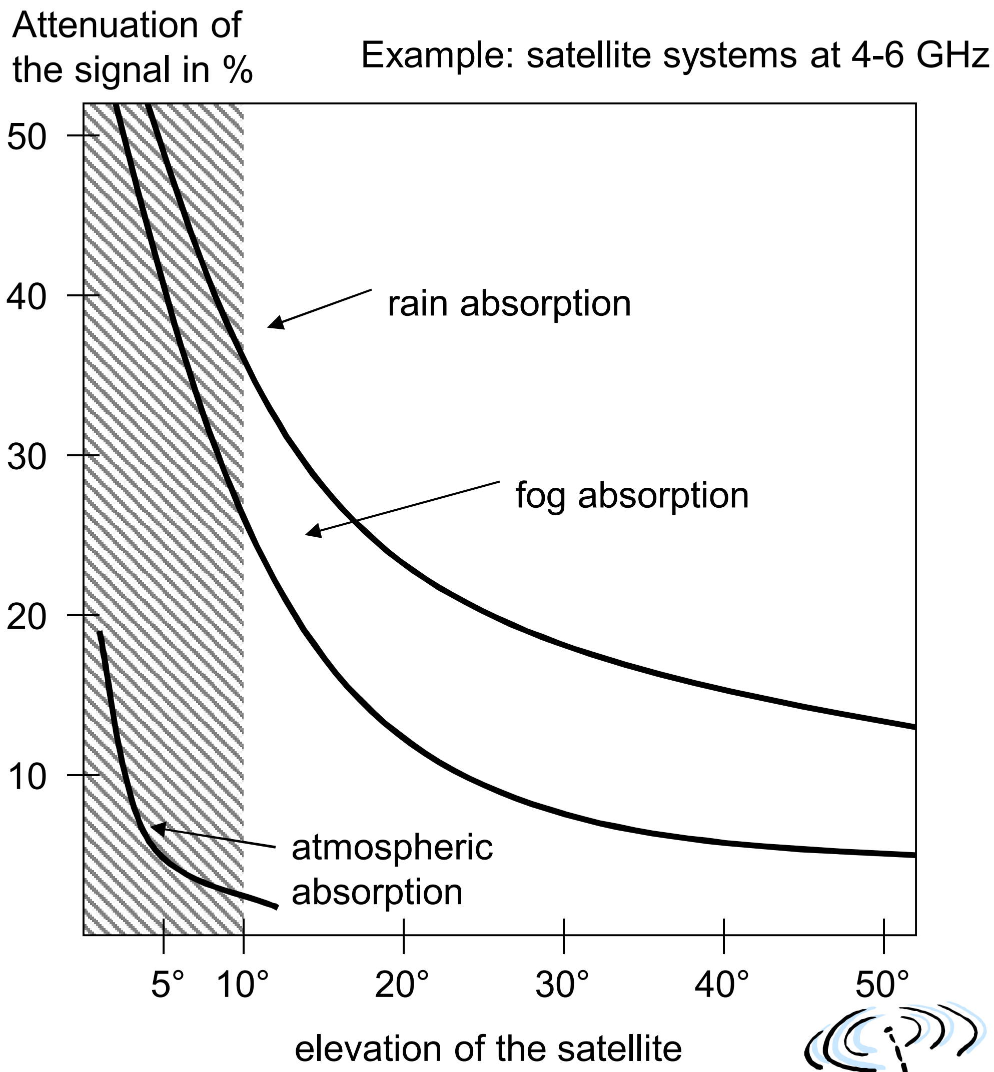
- varying strength of received signal due to multipath propagation
- interruptions due to shadowing of signal (no LOS)

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



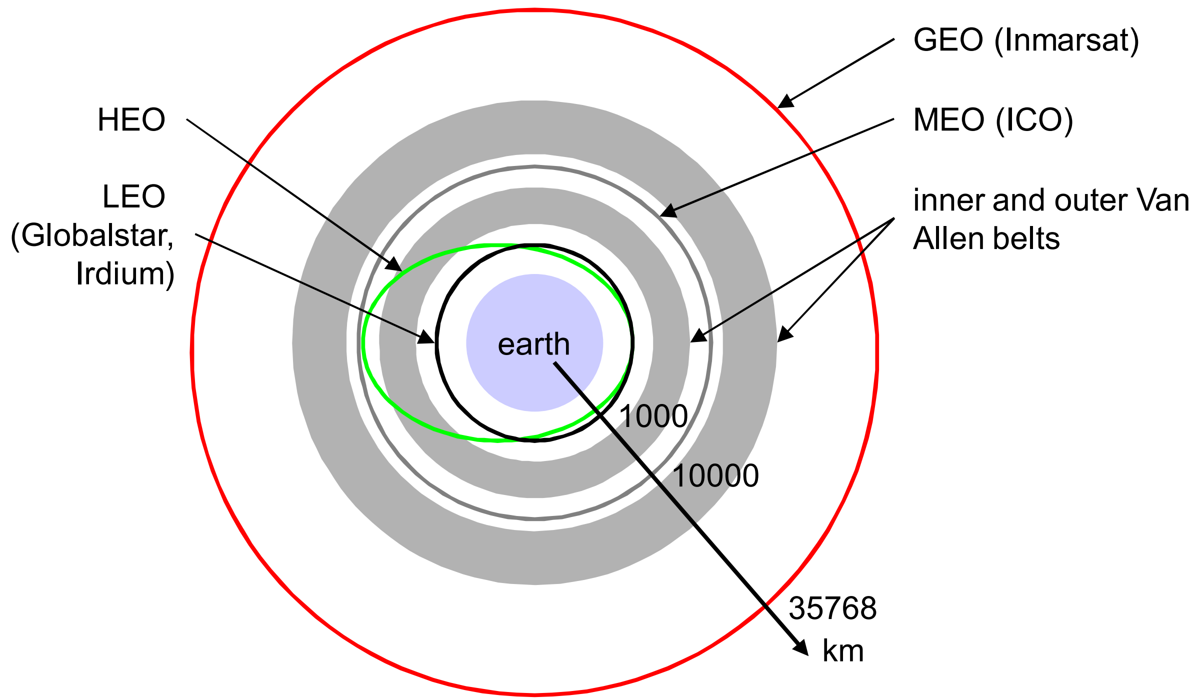


Orbits I

Four different types of satellite orbits can be identified depending on the shape and diameter of the orbit:

- GEO: geostationary orbit, ca. 36000 km above earth surface
- LEO (Low Earth Orbit): ca. 500 - 1500 km
- MEO (Medium Earth Orbit) or ICO (Intermediate Circular Orbit): ca. 6000 - 20000 km
- HEO (Highly Elliptical Orbit) elliptical orbits

Orbits II



Van-Allen-Belts:
ionized particles
2000 - 6000 km and
15000 - 30000 km
above earth surface

Geostationary 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

- ❑ fix 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 transmit power needed
- ❑ high latency due to long distance (ca. 275 ms)

➔ not useful for global coverage for small mobile phones and data transmission, typically used for radio and TV transmission

LEO systems

Orbit ca. 500 - 1500 km above earth surface

- visibility of a satellite ca. 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
- Lower longevity (atmospheric drag, inner Van-Allen-Belt)

Examples:

Iridium (start 1998, 66 satellites)

- Bankruptcy in 2000, deal with US DoD (free use, saving from “deorbiting”)

Globalstar (start 1999, 48 satellites)

- Not many customers (2001: 44000), low stand-by times for mobiles. Bankruptcy in 2002. Re-structured in 2004

MEO systems

Orbit ca. 5000 - 12000 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

Example:

ICO (Intermediate Circular Orbit, Inmarsat) start ca. 2000

- Bankruptcy, planned joint ventures with Teledesic, Ellipso – cancelled again, start planned for 2003. Ended-up deploying one GEO.

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

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
- updating VLR and SUMR

Calling a mobile station

- localization using HLR/VLR similar to GSM
- connection setup using the appropriate satellite

Handover in satellite systems

Several additional situations for handover in satellite systems compared to cellular terrestrial mobile phone networks caused by the movement of the satellites

- Intra satellite handover
  - handover from one spot beam to another
  - mobile station still in the footprint of the satellite, but in another cell
- Inter satellite handover
  - handover from one satellite to another satellite
  - mobile station leaves the footprint of one satellite
- Gateway handover
  - Handover from one gateway to another
  - mobile station still in the footprint of a satellite, but gateway leaves the footprint
- Inter system handover
  - Handover 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 etc.

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 (circa)]	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$

Link Budget

$$P_r = P_t - 92.4 - 20 \log F_{(GHz)} - 20 \log D_{(Km)} - A_t + G_t + G_r$$

G- Gain of antenna t – transmission; r – reception

At – atmospheric attenuation (dust, rain)

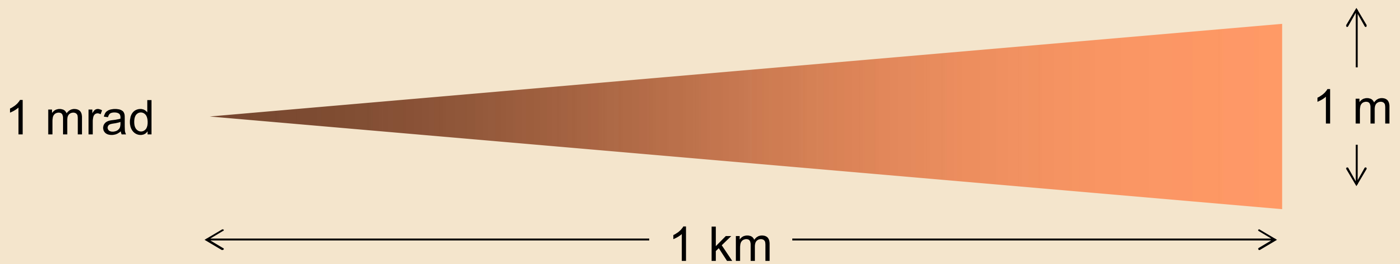
D = 36000 Km	-> 20 LogD = 91,1
F= 2 GHz	-> 20 LogF = 6
A=10 dB	
Gt = Gr = 30 dBi	
Pt = 40 dBm (10 W)	-> Pr = - 99,5 dBm

Angles - Divergence & Spot Size

1° ≈ 17 mrad → 1 mrad ≈ 0.0573°

Small angle approximation:

Angle (in milliradians) * Range (km)= Spot Size (m)

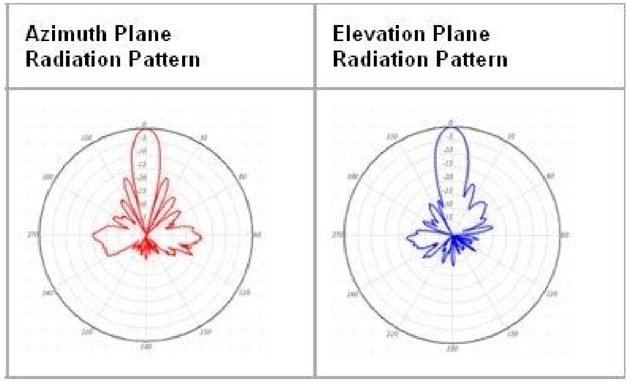


Divergence	Range	Spot Diameter
1 mrad	36000 km	36 Km
17 mrad (1 deg)	36000 km	612 Km

Antenna Gain vs Divergence

Gain(dBi) = 10 Log (2π / Div) = 10 Log (360º/Divº)

Isotropic Antenna -> Div = 2π / 360º (both Vert. and Hor.) Gain(dBi) = 0



Cisco AIR-ANT3338
21dBi Parabolic Dish
Azimuth 3dB BW =12º
Elevation 3dB BW =12º

Examples:

Div =2º	->	Gain(dBi) = 22,6 dBi (2x 22,6 if in both planes)
Div =4º	->	Gain(dBi) = 19,6 dBi
Div =8º	->	Gain(dBi) = 16,6 dBi
Div=12º	->	Gain(dBi) = 14,7 dBi (Vert and Hor: 14,7 x 2 = 29,4 dBi)

Nota: a antena da Cisco com Div= 12º tem 21 dBi de ganho, (vs 29.4 dBi teórico) devido a perdas noutras direcções.

Received Power based on Antenna Aperture Area (Ae)

$Ae = A_{physical} * \eta$ (η - Antenna efficiency 50%-80%)

$Pr = Pt - 10 \, Log(4 * Footprint / (PI^2 * Ae)) - At$

Pt = 40dBm (10W)

Footprint = 471 716 Km2 (PI x 387.5km x 387.5km) (Iberian peninsula 582 860 km2)

Aphy = 1m2 ; η = 50%

At = 10 dB

Pr = 40 – 115.6 -10 = - 85.6 dBm