Mobile Communications: Satellite Systems

Slide# 7

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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

History of Satellites

- **The First Satellites**

  The theory of satellites was simple enough - shoot something out into space at the right speed and on the correct trajectory and it will stay up there, orbiting Earth, for years - if not forever.

  If the orbit is the right distance in space the satellite will keep pace with the rotation of the Earth.

- **Pioneer Satellites (1957)**

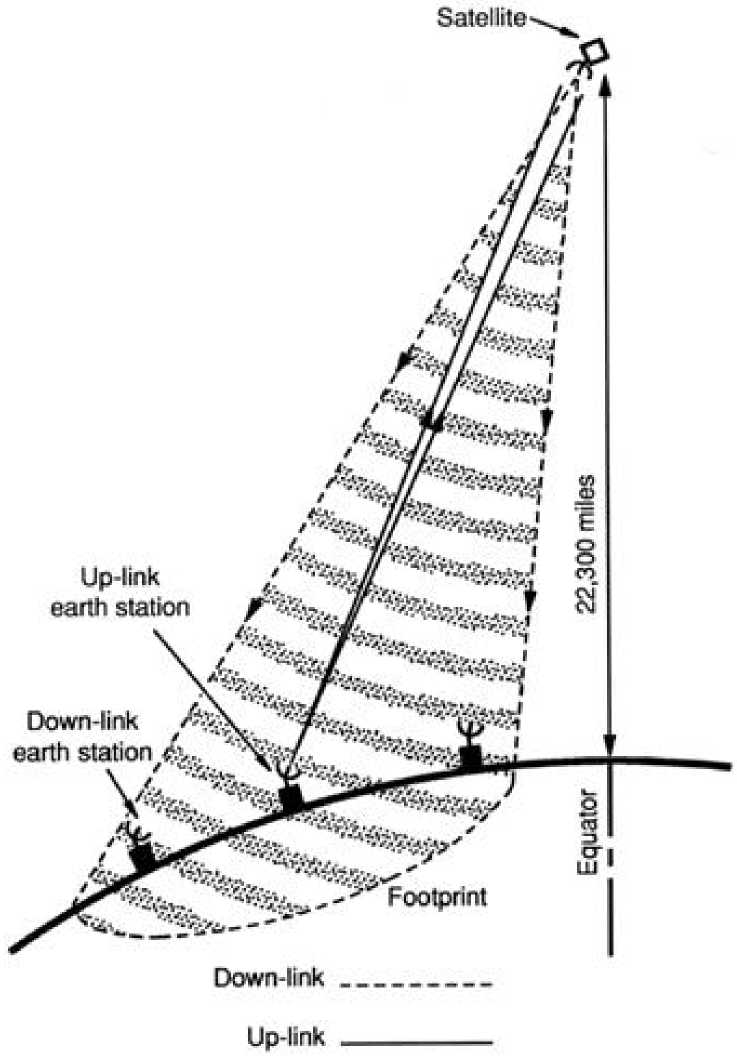
  Early in October 1957 communications stations started picking up a regular beeping noise coming from space.

  The signals were coming from Russia's Sputnik 1, the world's first man-made satellite.

  It was January 1958, before a Jupiter rocket successfully launched Explorer 1, the first American satellite.

How Satellites Work

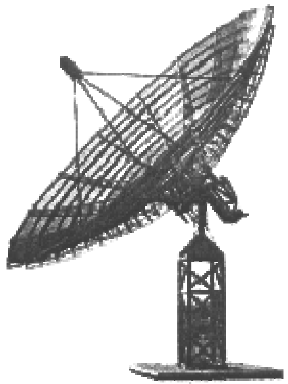
1. A Earth Station sends message in GHz range. (Uplink)
2. Satellite Receive and retransmit signals back. (Downlink)
3. Other Earth Stations receive message in useful strength area. (Footprint)



Satellite Frequency Bands and Antennas (Dishes)

- The size of Satellite Dishes (antennas) are related to the transmission frequency.
- There is a inverse relationship between frequency and wavelength.
- As wavelength increases (and frequency decreases), larger antennas (satellite dishes) are necessary to gather the signal.

Satellite Frequency Bands and Antennas (Dishes)



C-Band Ku-Band

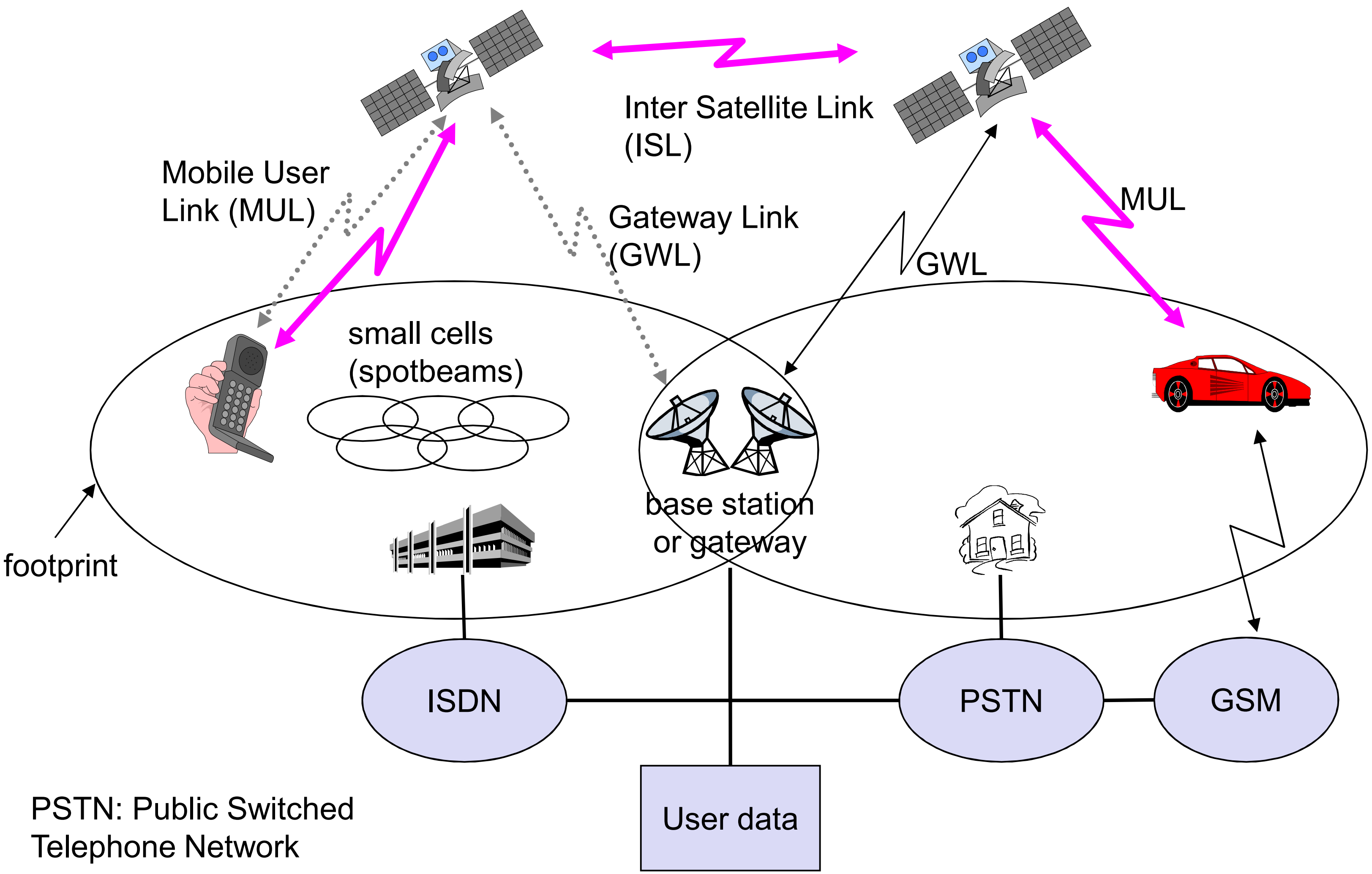
➢Most commonly used bands: C-band (4 to 8 GHz) , Ku-band (11 to 17 GHz) , and Ka-band (20 to 30 GHz).

Applications

- Traditionally
  - weather satellites
  - radio and TV broadcast satellites
  - military satellites
  - satellites for navigation and localization (e.g., GPS)
- Telecommunication
  - global telephone connections
  - backbone for global networks
  - connections for communication in remote places or underdeveloped areas
  - global mobile communication

➔ satellite systems to extend cellular phone systems

Classical satellite systems



PSTN: Public Switched
Telephone Network

Basics

Satellites in circular orbits

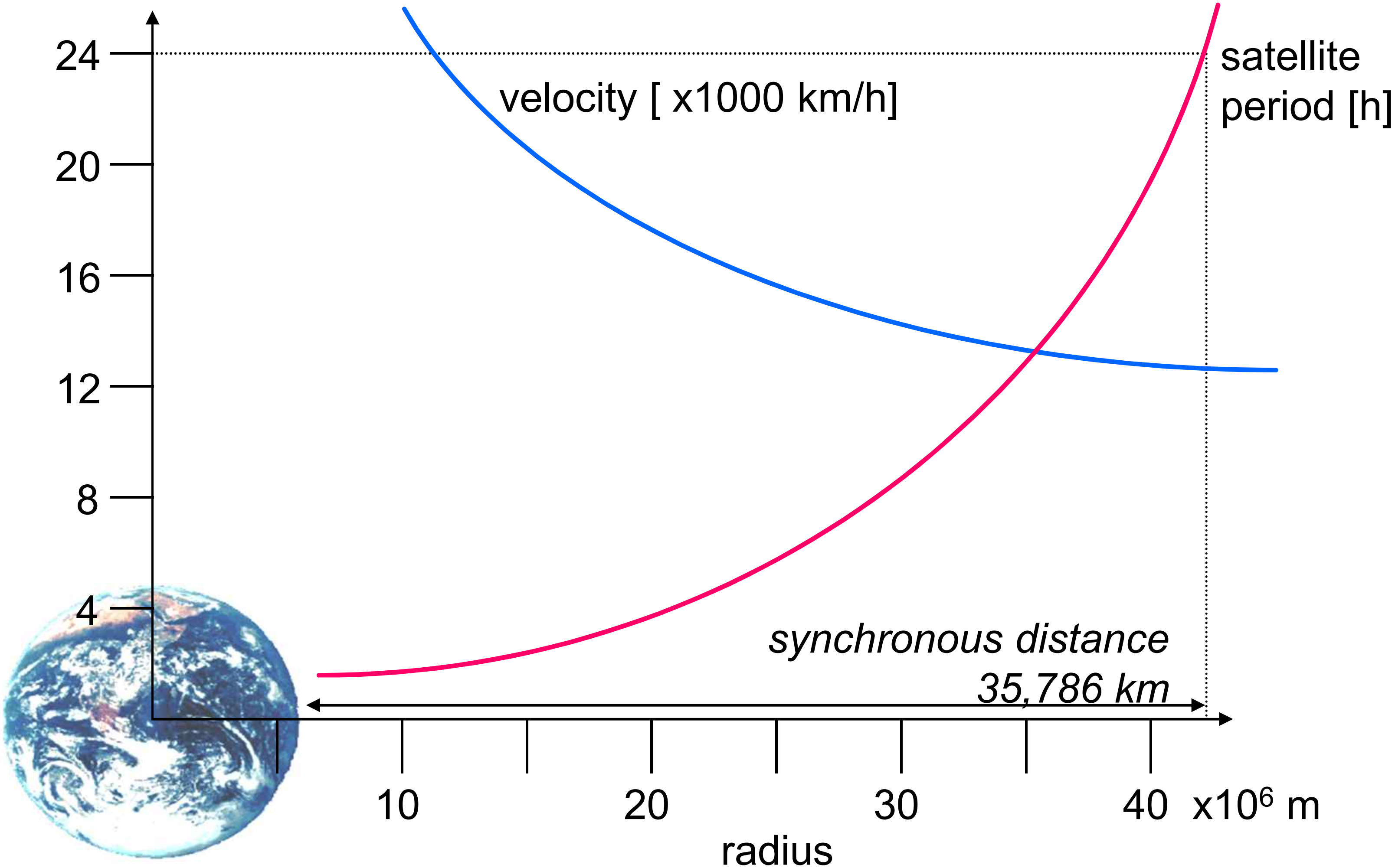
- attractive force $F_g = m\, g\, (R/r)^2$
- centrifugal force $F_c = m\, r\, \omega^2$
- m: mass of the satellite
- R: radius of the earth (R = 6370 km)
- r: distance to the center of the earth
- g: acceleration of gravity ($g = 9.81\ m/s^2$)
- ω: angular velocity ($\omega = 2\,\pi\, f$, f: rotation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

Stable orbit

- $F_g = F_c$

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

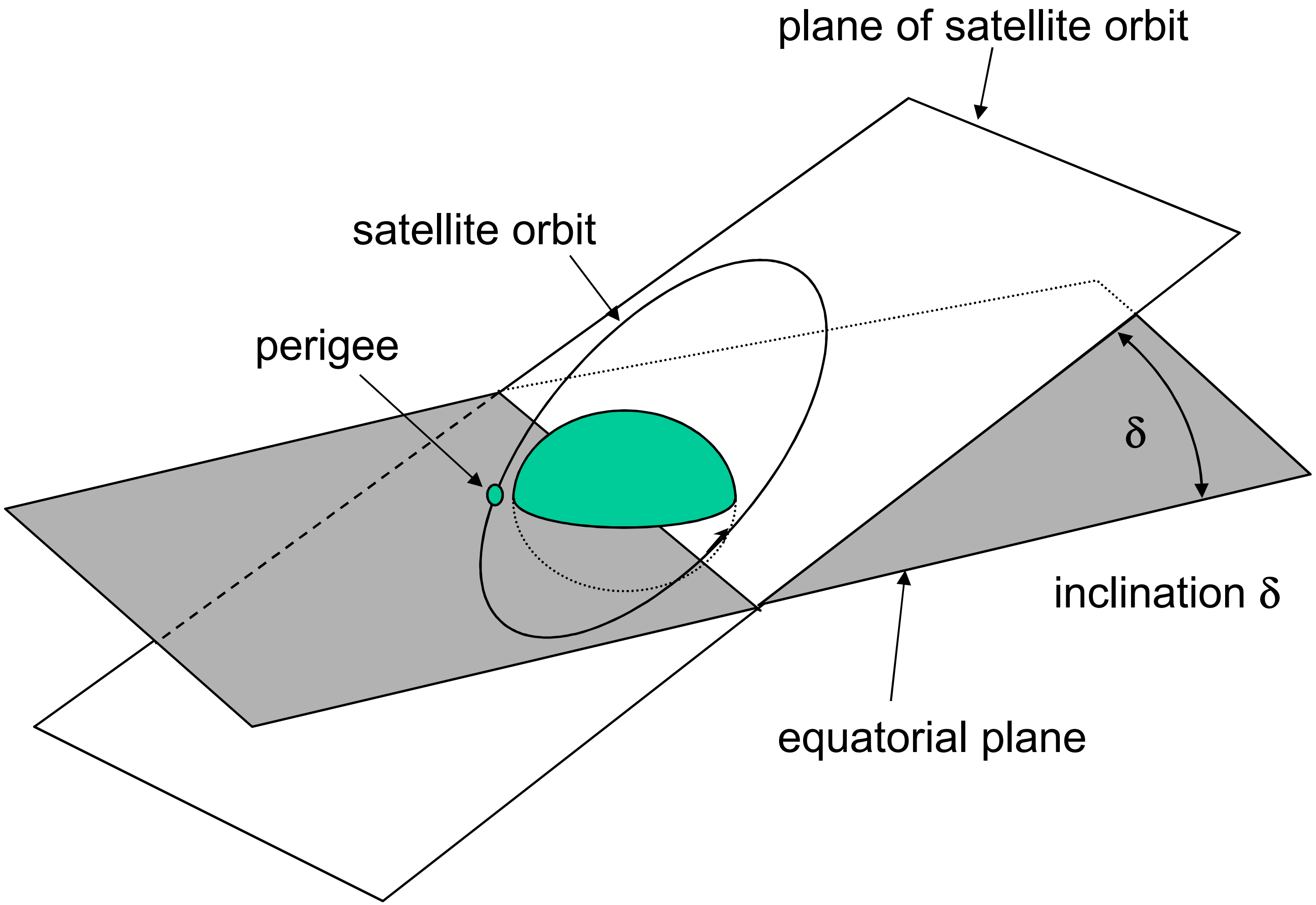
Satellite period and orbits



Basics

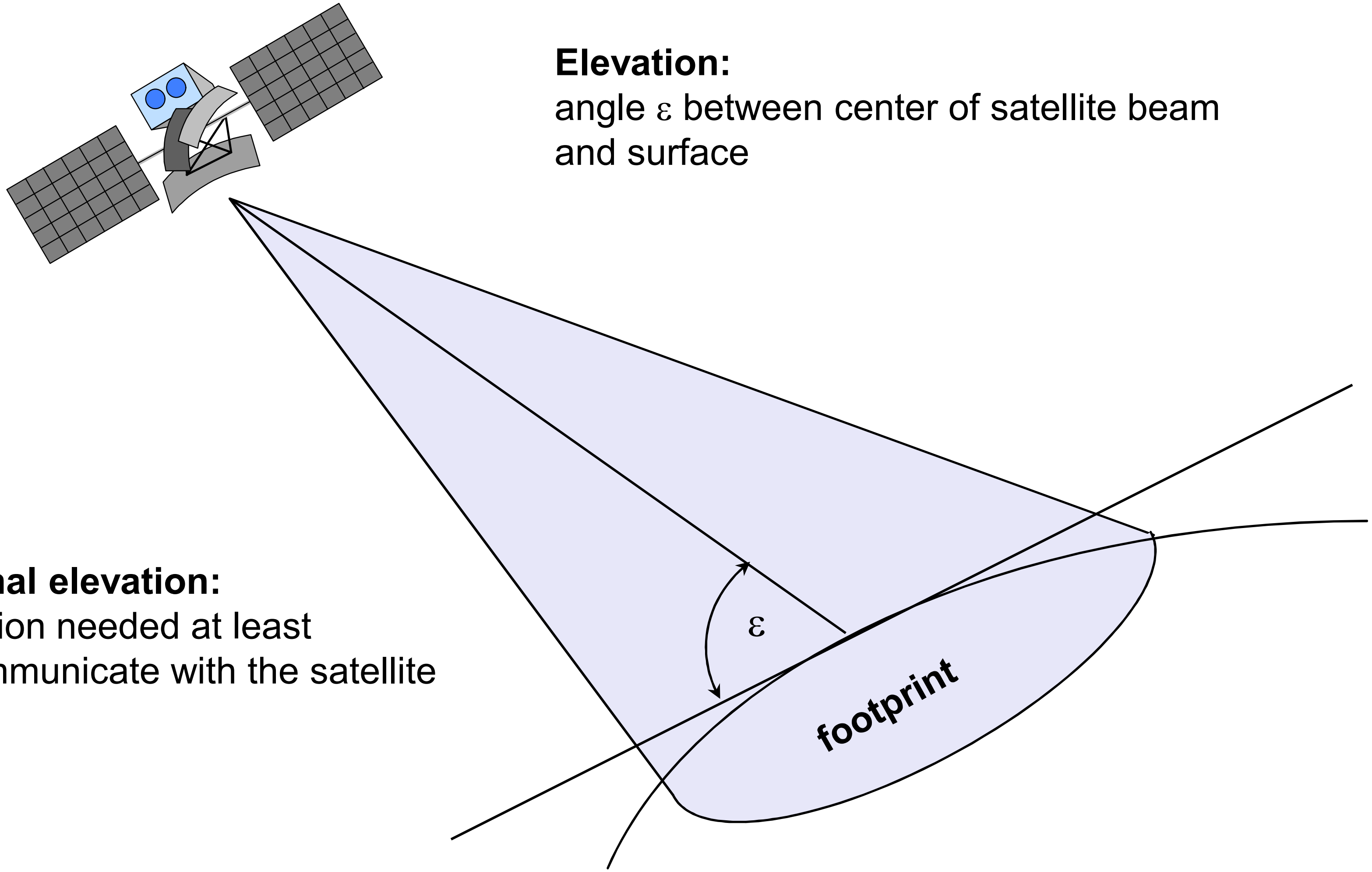
- elliptical or circular orbits
- complete rotation time depends on distance satellite-earth
- inclination: angle between orbit and equator
- elevation: angle between satellite and horizon
- LOS (Line of Sight) to the satellite necessary for connection
  - ➔ high elevation needed, less absorption due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

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

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

Examples:

Iridium (start 1998, 66 satellites)

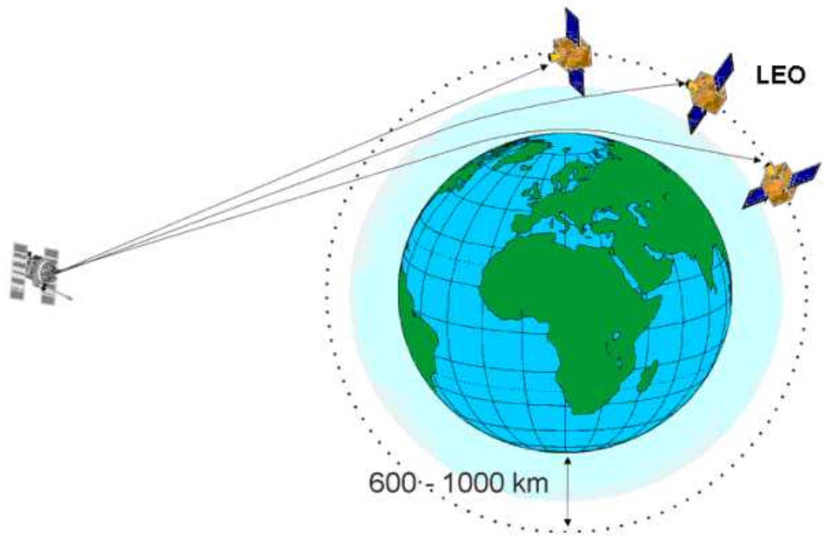
- Bankruptcy in 2000, deal with US DoD (free use, saving from "deorbiting")

Globalstar (start 1999, 48 satellites)

- Not many customers (2001: 44000), low stand-by times for mobiles

Low-Earth-Orbit (LEO)

- Altitude (375-1000 miles)
- Revolution time: 90 min - 3 hours.
- <u>Advantages:</u>
  - Reduces transmission delay
  - Eliminates need for bulky receiving equipment.
- <u>Disadvantages:</u>
  - Smaller coverage area.
  - Shorter life span (5-8 yrs.) than GEOs (10 yrs).
- Subdivisions: Little, Big, and Mega (Super) LEOs.



MEO systems

Orbit ca. 5000 - 12000 km above earth surface

comparison with LEO systems:

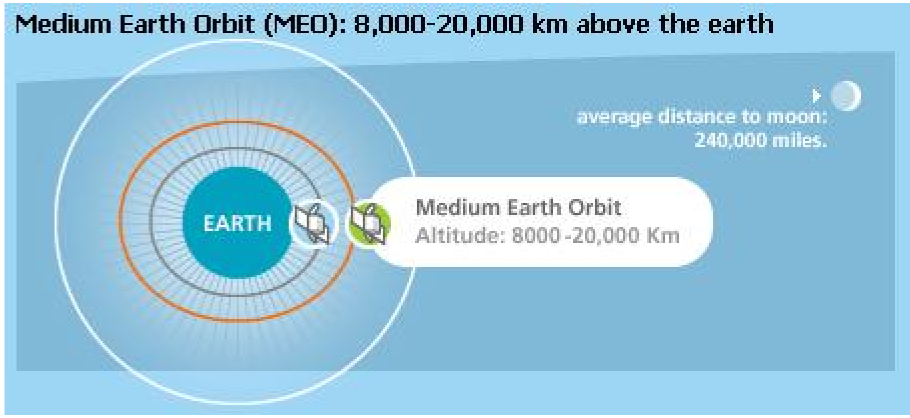
- slower moving satellites
- less satellites needed
- simpler system design
- for many connections no hand-over needed
- higher latency, ca. 70 - 80 ms
- higher sending power needed
- special antennas for small footprints needed

Example:

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

- Bankruptcy, planned joint ventures with Teledesic, Ellipso – cancelled again, start planned for 2003

Middle-Earth-Orbiting (MEO)



- MEOs orbits between the altitudes of 5,600 and 9,500 miles.
- These orbits are primarily reserved for communications satellites that cover the North and South Pole.

- Unlike the circular orbit of the geostationary satellites, MEOs are placed in an elliptical (oval-shaped) orbit.
- Approximately a dozen medium Earth orbiting satellites are necessary to provide continuous global coverage 24 hours a day.

Geostationary satellites

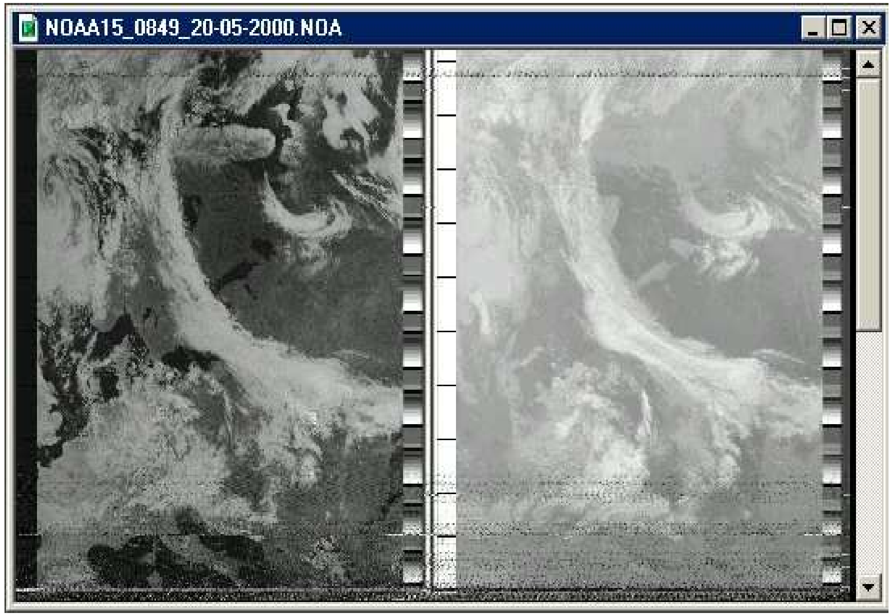
Orbit 35,786 km distance to earth surface, orbit in equatorial plane (inclination 0°)

➔ 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

GEOs and Weather



- The altitude is chosen so that it takes the satellite 24 hours to orbit the Earth once, which is also the rotation rate of the Earth.
- This produces the cloud animations you see on TV.
- Can take images approximately every minute.

Facts about GEOs

- Instruments on GEOs are designed to last 3-9 years.
- Measurements that are taken are in the form of electrical voltages that are digitized, and then transmitted to receiving stations on the ground.
- Instruments usually have:
  - Small telescope or antenna.
  - A scanning mechanism.
  - One or more detectors that detect either visible, infrared, or microwave radiation.

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

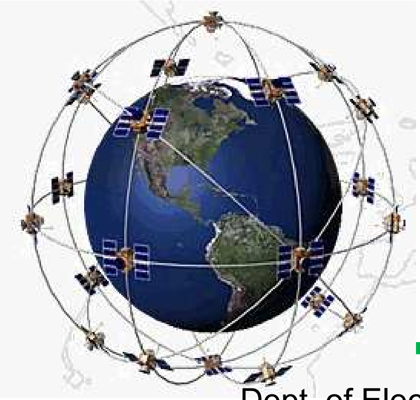
Calling a mobile station

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

GPS: What is it ?

A constellation of 24 satellites

- The Global Positioning System (GPS) is a worldwide radio-navigation system formed from a constellation of 24 satellites and their ground stations.
- They are constantly moving, making two complete orbits in less than 24 hours.
- These satellites are traveling at speeds of roughly 7,000 miles an hour.



GPS Satellites

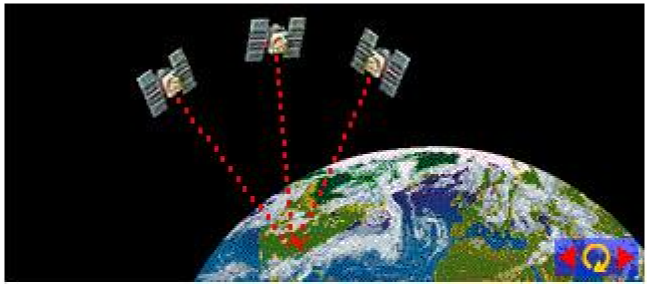
Name:	NAVSTAR
Manufacturer:	Rockwell International
Altitude:	10,900 nautical miles
Weight:	1900 lbs (in orbit)
Size:	17 ft with solar panels extended
Orbital Period:	12 hours
Orbital Plane:	55 degrees to equatorial plane
Planned Lifespan:	7.5 years
Current constellation:	24 Block II production satellites

The spacing of the satellites are arranged so that a minimum of five satellites are in view from every point on the globe.

GPS: How it works

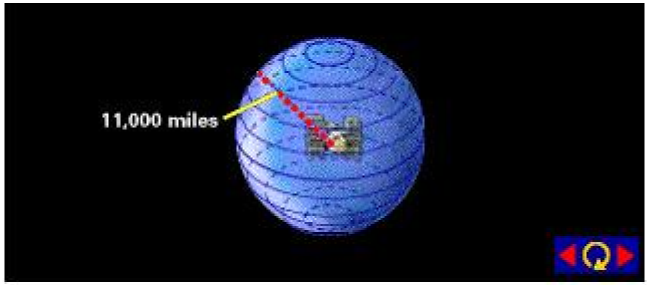
Satellites are reference points for locations on Earth

- The whole idea behind GPS is to use satellites in space as reference points for locations here on earth.
- GPS satellites use a "triangulate," system where the GPS receiver measures distance using the travel time of radio signals.
- By using triangulation, we can accurately measure our distance and find out position from three satellites position anywhere on earth.



EX. THE BIG PICTURE

If a particular satellite is 11,000 miles above it. Then we know that it's radius is 11,000 miles!



EX. THE BIG PICTURE

Basic calculations measuring distance

Velocity * Time = Distance

Velocity = speed of light (186,000 miles per second.)

Time = a lot of analysis and calculations!

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.