Satellites

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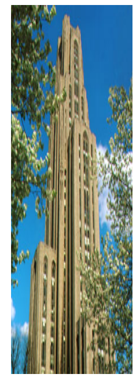
Slides 17



Satellite Applications

- Over 3500 Satellites in use today - industry overall revenues of $2.3 billion in 2004

- Telecommunications
  - global telephone connections } being replaced by fiber optics
  - backbone for global networks }
  - connections for communication in remote places or underdeveloped areas
  - global mobile communications
- Other Applications
  - weather
  - radio and TV broadcast satellites
  - Earth observation (climate change, agricultural, etc.)
  - military: surveillance, imaging, intelligence, early warning
  - Navigation and localization: aeronautic, nautical, etc., (e.g., GPS, NavStar)

Satellite History

A Selective Satellite Chronology

- 1945 Arthur C. Clarke – head of British Interplanetary Society publishes article: "Extra-Terrestrial Relays" defines basic satellite concept - latter fame as Sci-Fi author
- 1955 John R. Pierce (AT&T researcher) publishes Article: "Orbital Radio Relays" defines technical aspects for global telephony
- 1957 Sputnik: Russia launches the first earth satellite.
- 1960 First reflecting communication satellite ECHO – aluminum coated balloon

http://www.hq.nasa.gov/office/pao/History/satcomhistory.html

Satellite History

- 1962 AT&T TELSTAR (first active satellite) and RELAY launched (MEO) - for voice/television/data
- 1962 Communications Satellite Act (U.S.)
- 1963 SYNCOM launched – first geosynchronous orbit satellite
- 1964 INTELSAT formed
  International Telecommunications Satellite Organization (part of UN) - aim provide global telecommunications connectivity
- 1965 COMSAT's EARLY BIRD: 1st commercial communications satellite: 240 duplex telephone channels or 1 TV channel, 1.5 years lifetime
- 1969 INTELSAT-III series provides global coverage
- 1972 ANIK: 1st Domestic Communications Satellite (Canada)
- 1974 WESTAR: 1st U.S. Domestic Communications Satellite
- 1975 RCA SATCOM: 1st operational body-stabilized Satellite
- 1976 MARISAT: 1st mobile communications satellite
- 1979 INMARSAT formed.

Satellite History

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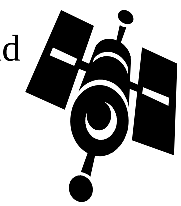
1982 first mobile satellite telephone system INMARSAT-A

1988 first satellite system for mobile phones and data communication INMARSAT-C

1993 first digital satellite telephone system

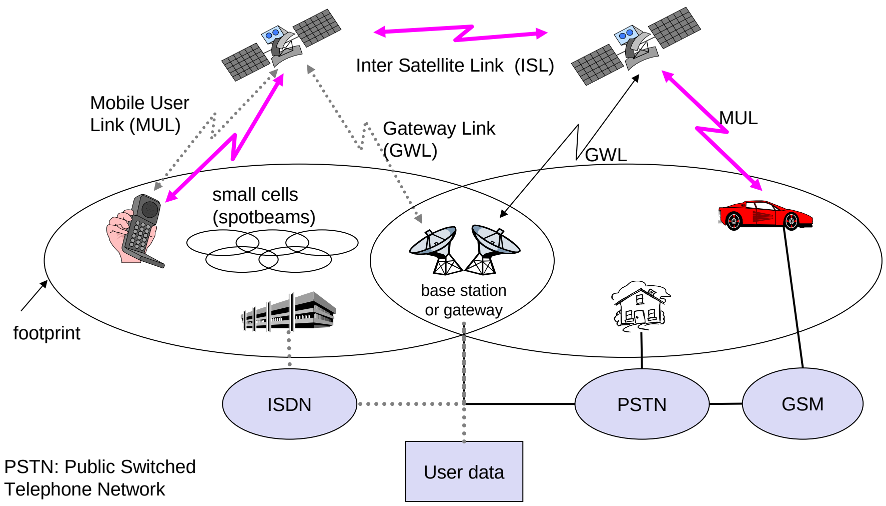
1998 global satellite systems for small mobile phones



Satellite Basics

- Earth Stations – antenna systems on or near earth
- Uplink – transmission from an earth station to a satellite
- Downlink – transmission from a satellite to an earth station
- Typically separated frequencies for uplink and downlink (FDD)
- Transponder – electronics in the satellite that convert uplink signals to downlink signals
  - transparent transponder: only shift of frequencies (Bent Pipe)
  - regenerative transponder: additionally signal regeneration and formatting) Processing Satellite

Typical Satellite System



Satellite Classification

- Can Characterize Satellites on variety of Factors
- Frequency:
  - Spectrum
- Orbit:
  - Height: (GEO, HEO, MEO, LEO)
  - Pattern: elliptical vs. circular, inclination, etc.
- Multiple Access Method:
  - TDMA, FDMA, CDMA
- Satellite Capabilities
  - Bent Pipe vs. On board Processing
- Coverage and Usage Type
  - Coverage: global, regional, national
  - Usage: broadcast, two-way, mobile, etc.

U.S. Satellite Frequency Bands

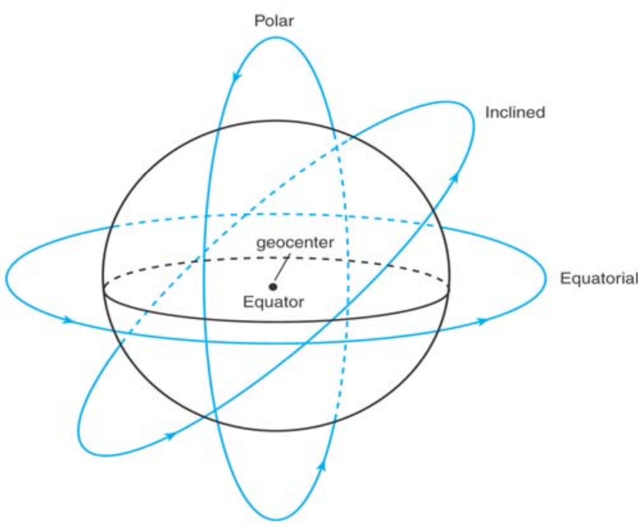
Licensed Spectrum - only

Band	Frequency Range	Total Bandwidth	General Application
L	1 to 2 GHz	1 GHz	Mobile satellite service (MSS)
S	2 to 4 GHz	2 GHz	MSS, NASA, deep space research
C	4 to 8 GHz	4 GHz	Fixed satellite service (FSS)
X	8 to 12.5 GHz	4.5 GHz	FSS military, terrestrial earth exploration, and meteorological satellites
Ku	12.5 to 18 GHz	5.5 GHz	FSS, broadcast satellite service (BSS)
K	18 to 26.5 GHz	8.5 GHz	BSS, FSS
Ka	26.5 to 40 GHz	13.5 GHz	FSS

Classification of Satellite Orbits

- Circular or elliptical orbit
  - Circular with center at earth's center
  - Elliptical with one foci at earth's center
- Orbit around earth in different planes
  - Equatorial orbit above earth's equator
  - Polar orbit passes over both poles
  - Other orbits referred to as inclined orbits
- Altitude of satellites
  - Geostationary orbit (GEO)
  - High earth orbit (HEO)
  - Medium earth orbit (MEO)
  - Low earth orbit (LEO)

Orbital Pattern



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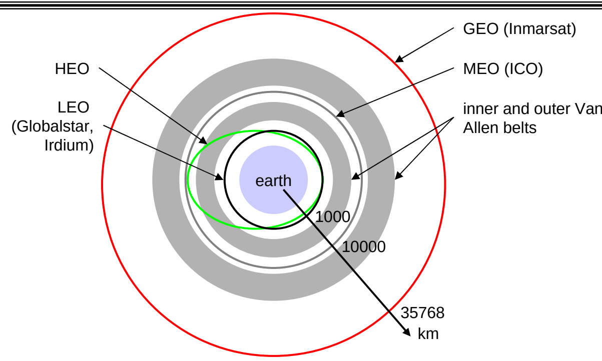
12

Orbital Height

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

LEOs allow intra-satellite switched connections
Require smart satellites



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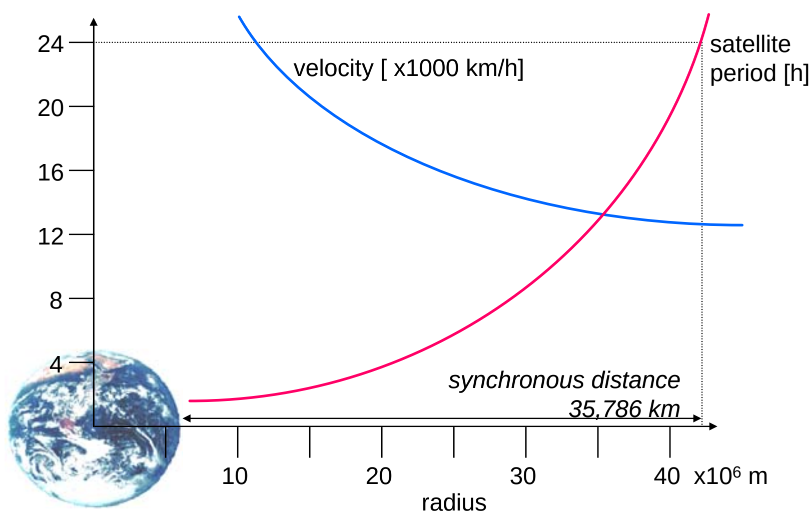
13

Orbit 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
  - $F_g = F_c$

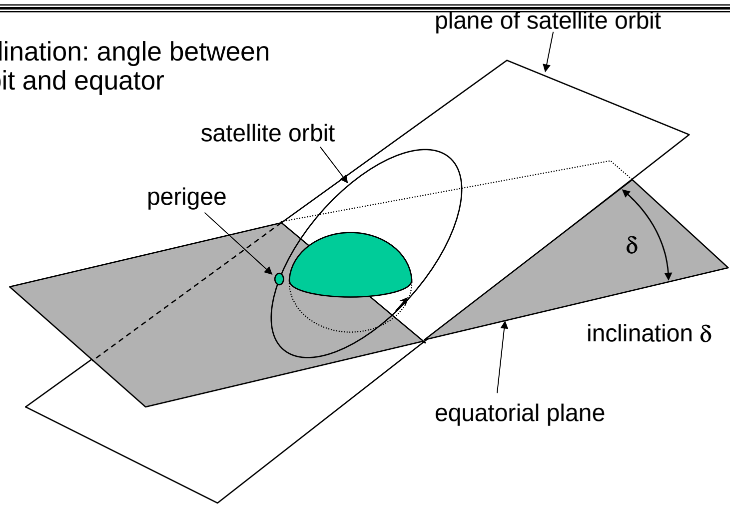
$$r = \sqrt[3]{\frac{gR^2}{(2\pi f)^2}}$$

Satellite period and orbits



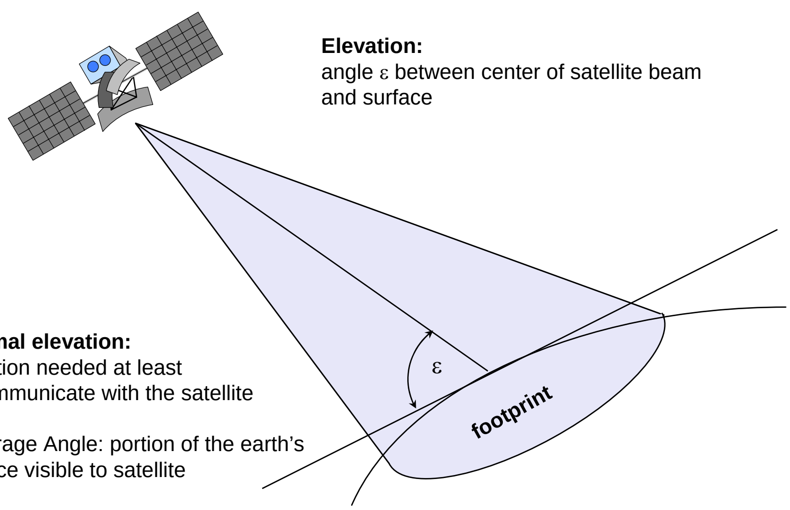
Inclination

inclination: angle between
orbit and equator



Elevation

Elevation:
angle ε between center of satellite beam
and surface



minimal elevation:
elevation needed at least
to communicate with the satellite

Coverage Angle: portion of the earth's
Surface visible to satellite

Satellite Footprint

Footprint: geographic area where communication possible

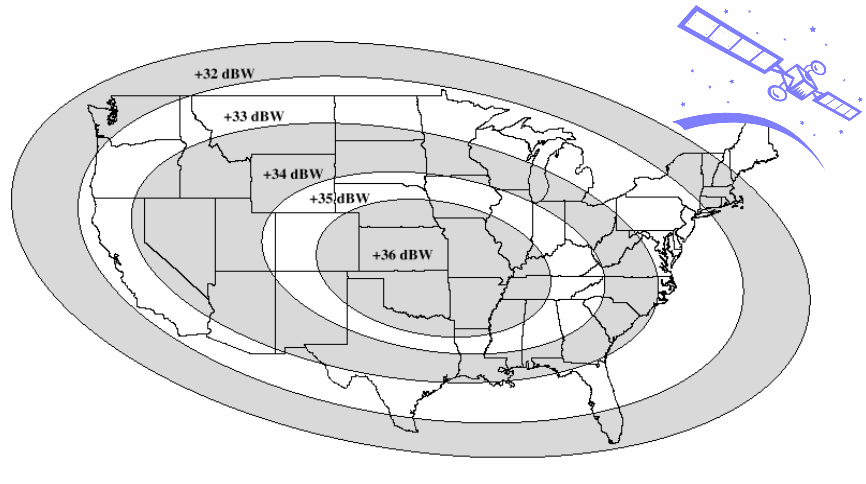


Figure 9.6 Typical Satellite Footprint

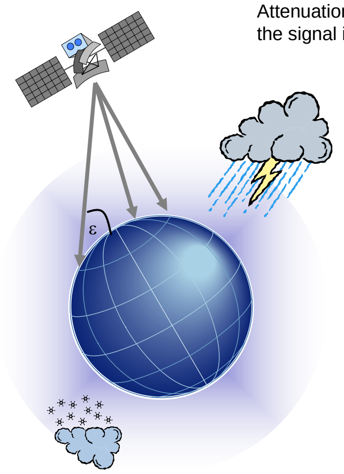
Link budget of satellites

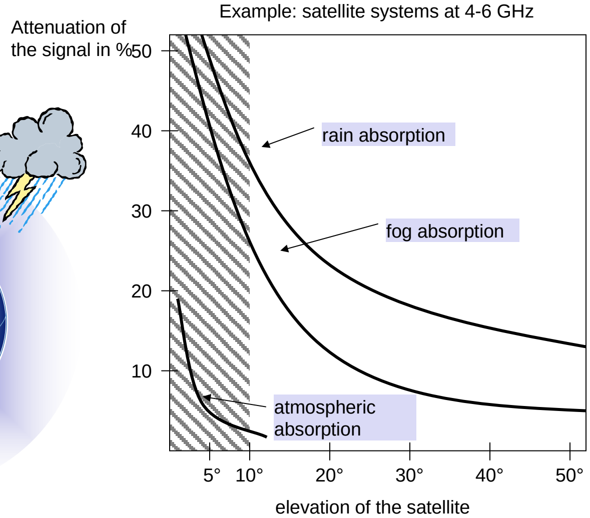
- Parameters like attenuation or received power determined by four parameters:
- sending power
- gain of sending antenna
- distance between sender and receiver
- gain of receiving antenna
- Problems
- varying strength of received signal due to multipath propagation
- interruptions due to shadowing of signal (no LOS)
- Typically need LOS in satellite systems
- 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 transmit power

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

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

Atmospheric attenuation

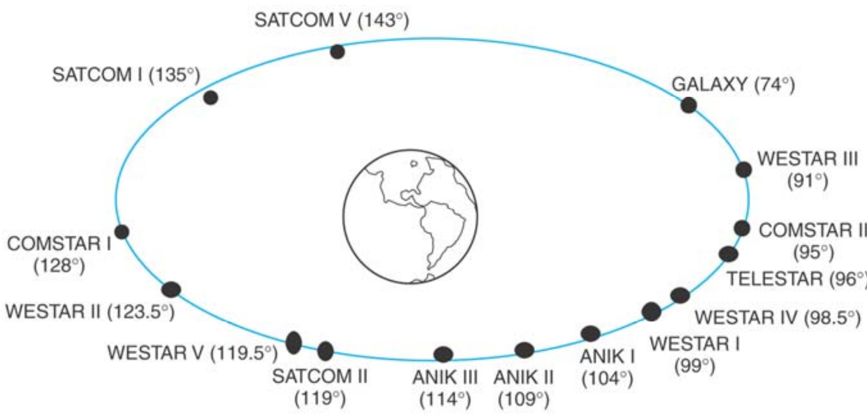




Geostationary satellites

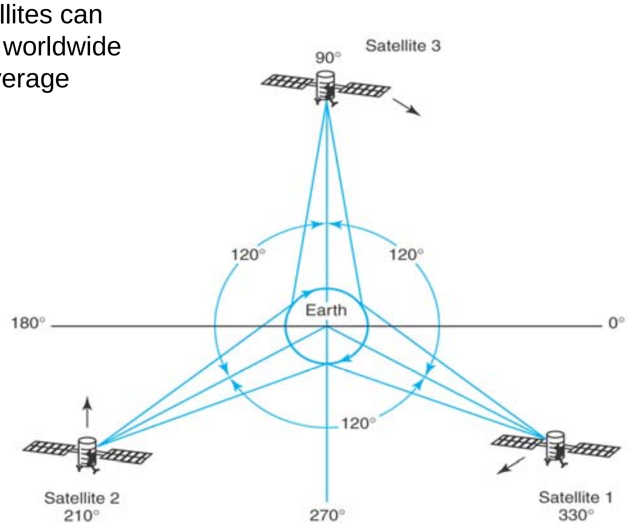
- Orbit 35.786 km distance to earth surface, orbit in equatorial plane (inclination 0°)
- ➔ complete rotation exactly one day, satellite is synchronous to earth rotation
- Advantages of the GEO orbit
  - No problem with frequency changes
  - Tracking of the satellite is simplified
  - High coverage area with large footprint (up to 34% of earth surface!),
- Disadvantages of the GEO orbit
  - Weak signal after traveling over 35,000 km → high transmit power
  - Bad elevations in areas with latitude above 60° due to fixed position above the equator
  - Polar regions are poorly served
  - high latency due to long distance (~ 275 ms)
- Geosynchronous orbit – now called Clarke orbit

Satellites in geosynchronous earth orbits



Three geosynchronous satellites in Clarke orbits

3 satellites can provide worldwide coverage



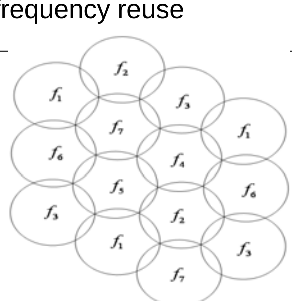
GEO Systems

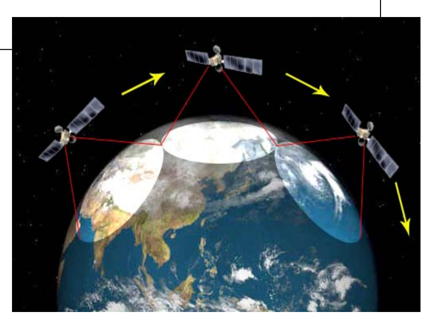
- Example
- INMARSAT – GEO system originally for maritime communication
  - handheld phone not available due to high power required
  - focus now on data service as well as telephony



LEO systems

- Orbit 500 - 1500 km above earth surface
  - visibility of a satellite 10 - 40 minutes
  - latency comparable with terrestrial long distance connections, ca. 5 - 10 ms
  - many satellites necessary for global coverage
  - handover necessary from one satellite to another
  - more complex systems due to moving satellites
  - Note satellites use spot beams with smaller footprints - allows frequency reuse





LEO Systems

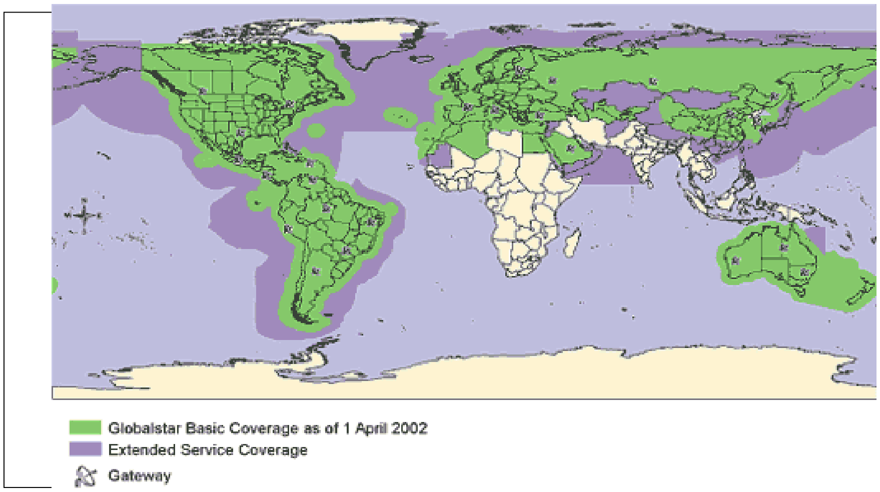
- Examples:
  - Iridium (start 1998, 66 satellites in 11 orbits – 6 in each orbit
    - Smart system with ISL links
  - Globalstar (start 1999, 48 satellites in 8 orbits – 6 in each orbit)
    - Bent pipe system

GlobalStar

- Intended as adjunct to cellular
  - Dual Mode, dual band phones
    - IS95 – Globalstar,
    - Phone first tries to find cellular service
    - If not available – home on to satellite
  - LEO system 48 satellites
    - 8 orbital planes – 6 satellites each
  - Cheap Bent pipe system

QUALCOMM GSP-1600

Global Star



Routing Connections

- In LEO networks need to route connections through the netework
- Some LEOs use inter satellite links (ISL) (e.g., Iridium)
  - 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 or data connections
- Problems:
  - more complex focusing of antennas between satellites
  - high system complexity due to moving routers
  - higher fuel consumption
  - thus shorter lifetime
- Other systems use multiple gateways on the earth and additionally terrestrial networks (e.g, cellular networks when in range)

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

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MEO systems

- Orbit ca. 5000 - 12000 km above earth surface
- comparison with LEO systems:
- slower moving satellites
- Diameter of coverage is 10,000 to 15,000 km
  - 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
- Orbit period of 6 hours or more
- Maximum satellite visible time is a few hours

- Example:
- Ellipso/ICO

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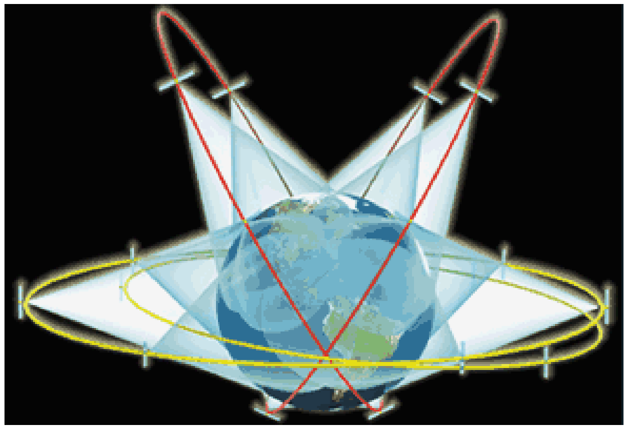
Ellispso System

- Set of 17 satellites to provide worldwide coverage with dual mode cellular/satellite phones

Satellite to mobile2165 - 2200 MHz S band
Mobile to satellite1990 - 2025 MHz S band
Satellite to gateway 6775 - 7075 MHz C band
Gateway to satellite15400-15700 MHz Ku band



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	Ellipso/ICO	Teledesic
# satellites	66 + 6	48 + 4	17 + 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$
Access	TDD/TDMA	FDD/CDMA	CDMA	FDMA/TDMA

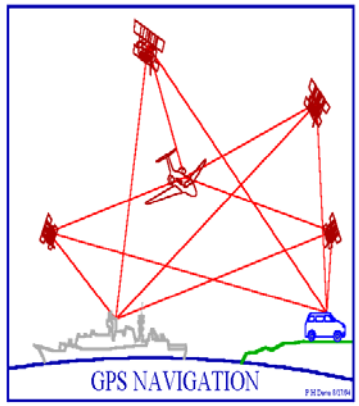
Global Position System

- In 1973, the US Air Force proposed a new system for navigation using MEO satellites
- The system is known as: *Navigation System with Timing and Ranging: Global Positioning System* or *NAVSTAR GPS*
- Full Operational Capability declared by the Secretary of Defense at 00:01 hours on July 17, 1995

http://www.utexas.edu/depts/grg/gcraft/notes/gps/gps.html

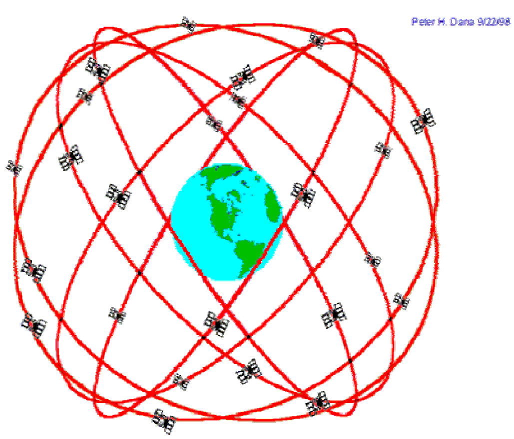
NAVSTAR GPS Goals

- What time is it?
- What is my position (including attitude)?
- What is my velocity?
- Other Goals:
  - What is the local time?
  - When is sunrise and sunset?
  - What is the distance between two points?
  - What is my estimated time of arrival?



Space Segment

- System consists of 24 satellites: 21 in use and 3 spares
- Altitude: 20,200 Km with periods of 12 hr (MEOs).
- Current Satellites: $25,000,000, 2000 KG
- Hydrogen maser atomic clocks - lose one second every 2,739,000 million years



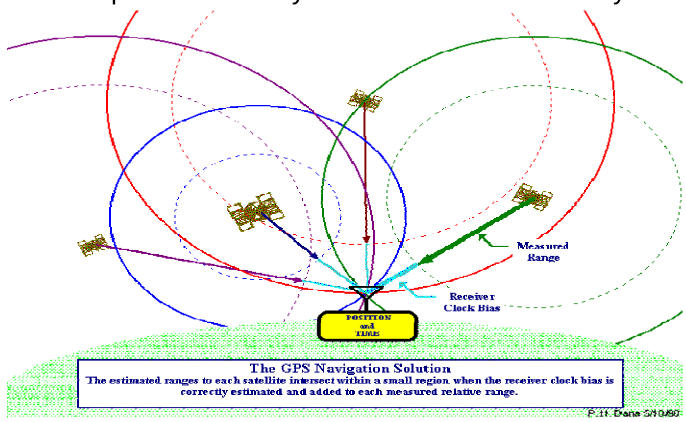
GPS Nominal Constellation
24 Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,200 km Altitudes, 55 Degree Inclination

Control Segment

- Master Control Station is located at the Consolidated Space Operations Center (CSOC) at Flacon Air Force Station near, Colorado Springs, Colorado
- Tracks the satellites for orbit and clock determination and manages Denial Of Availability (DOA)

GSP System: Overview

- Satellites simultaneously broadcast beacon messages (called navigation messages)
- A GPS receiver measures time of arrival from the satellites, and then uses "trilateration" to determine its position
- 4[th] satellite improves accuracy as satellite clocks not in synch

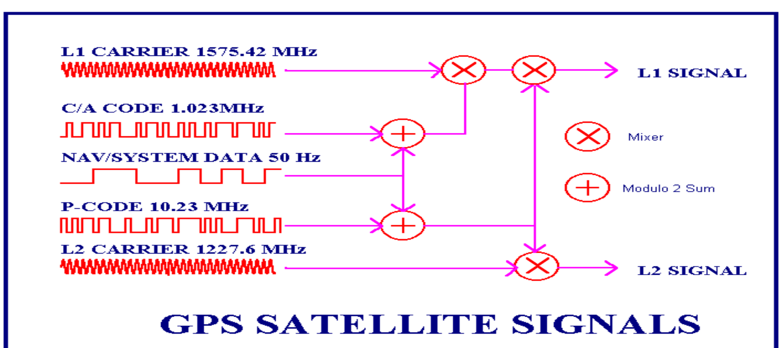


GPS Satellite Transmissions

- All 24 GPS satellites transmit on the same frequencies BUT use different codes
  - i.e., Direct Sequence Spread Spectrum (DSSS), and
  - Code Division Multiple Access (CDMA)
- Two carriers: L1 = 1575.42 MHz, L2 = 1227.60 MHz
- Use BPSK modulation

GPS Identifying Codes

- Two types of codes
  - C/A Code - Coarse/Acquisition Code available for civilian use on L1 provides 300 m chip length
  - P Code - Precise Code on L1 and L2 used by the military provides 3 m chip length
    - encrypted P code (called Y code) provides selected availability and anti-spoofing



GPS User

- Typical receiver: C/A code on L1
- During the "acquisition" time you are receiving decoding the navigation message on L1
- Navigation Message - transmitted on both L1 and L2 at 50 bps
  - each frame is 1500 bits; transmitted at minute and half-minute
- The receiver then reads the timing information and computes the "pseudo-ranges"
- GPS can be jammed by sophisticated adversaries
- Obstructions to GPS satellites common
    - each node needs LOS to 4 satellites
    - GPS satellites not necessarily overhead, e.g., urban canyon, indoors, and underground

Satellite Summary

- Applications of Satellites
- Basic system structure
- Types of Satellites
- Industry in flux – move from telecommunications to data oriented applications