CSE 4215/5431: Mobile Communications

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Course page: http://www.cse.yorku.ca/course/4215

Some slides are adapted from the Schiller book website

IEEE 802.15 – future developments 3

- 802.15.4: Low-Rate, Very Low-Power
  - Low data rate solution with multi-month to multi-year battery life and very low complexity
  - Potential applications are sensors, interactive toys, smart badges, remote controls, and home automation
  - Data rates of 20-250 kbit/s, latency down to 15 ms
  - Master-Slave or Peer-to-Peer operation
  - Up to 254 devices or 64516 simpler nodes
  - Support for critical latency devices, such as joysticks
  - CSMA/CA channel access (data centric), slotted (beacon) or unslotted
  - Automatic network establishment by the PAN coordinator
  - Dynamic device addressing, flexible addressing format
  - Full handshake-based protocol for transfer reliability
  - Power management to ensure low power consumption
  - 16 channels in the 2.4 GHz ISM band, 10 channels in the 915 MHz US ISM band and one channel in the European 868 MHz band
- Basis of the ZigBee technology – www.zigbee.org

ZigBee

- Relation to 802.15.4 similar to Bluetooth / 802.15.1
- Pushed by Chipcon (now TI), ember, freescale (Motorola), Honeywell, Mitsubishi, Motorola, Philips, Samsung…
- More than 260 members
  - about 15 promoters, 133 participants, 111 adopters
  - must be member to commercially use ZigBee spec
- ZigBee platforms comprise
  - IEEE 802.15.4 for layers 1 and 2
  - ZigBee protocol stack up to the applications

IEEE 802.15 – future developments 4

- 802.15.4a:
  - Alternative PHY with lower data rate as extension to 802.15.4
  - Properties: precise localization (< 1m precision), extremely low power consumption, longer range
  - Two PHY alternatives
    - UWB (Ultra Wideband): ultra short pulses, communication and localization
    - CSS (Chirp Spread Spectrum): communication only
- 802.15.4b, c, d, e, f, g:
  - Extensions, corrections, and clarifications regarding 802.15.4
  - Usage of new bands, more flexible security mechanisms
  - RFID, smart utility neighborhood (high scalability)
- 802.15.5: Mesh Networking
  - Partial meshes, full meshes
  - Range extension, more robustness, longer battery live
- 802.15.6: Body Area Networks
  - Low power networks e.g. for medical or entertainment use
- 802.15.7: Visible Light Communication

- Not all these working groups really create a standard, not all standards will be found in products later …

Other IEEE standards for mobile communications

- IEEE 802.16: Broadband Wireless Access / WirelessMAN / WiMax
  - Wireless distribution system, e.g., for the last mile, alternative to DSL
  - 75 Mbit/s up to 50 km LOS, up to 10 km NLOS; 2-66 GHz band
  - Initial standards without roaming or mobility support
  - 802.16e adds mobility support, allows for roaming at 150 km/h
- IEEE 802.20: Mobile Broadband Wireless Access (MBWA)
  - Licensed bands < 3.5 GHz, optimized for IP traffic
  - Peak rate > 1 Mbit/s per user
  - Different mobility classes up to 250 km/h and ranges up to 15 km
  - Relation to 802.16e unclear
- IEEE 802.21: Media Independent Handover Interoperability
  - Standardize handover between different 802.x and/or non 802 networks
- IEEE 802.22: Wireless Regional Area Networks (WRAN)
  - Radio-based PHY/MAC for use by license-exempt devices on a non-interfering basis in spectrum that is allocated to the TV Broadcast Service

RF Controllers – ISM bands

- Data rate
  - Typically up to 115 kbit/s (serial interface)
- Transmission range
  - 5-100 m, depending on power (typically 10-500 mW)
- Frequency
  - Typ. 27 (EU, US), 315 (US), 418 (EU), 426 (Japan), 433 (EU), 868 (EU), 915 (US) MHz (depending on regulations)
- Security
  - Some products with added processors
- Cost
  - Cheap
  - Availability: Many products, vendors
- Connection set-up time
  - N/A
- Quality of Service
  - none
- Manageability
  - Very simple, same as serial interface
- Special Advantages/Disadvantages
  - Advantage: very low cost, large experience, high volume available
  - Disadvantage: no QoS, crowded ISM bands (particularly 27 and 433 MHz), typically no Medium Access Control, 418 MHz experiences interference with TETRA

RFID – Radio Frequency Identification (1)

- Data rate
  - Transmission of ID only (e.g., 48 bit, 64kbit, 1 Mbit)
  - 9.6 – 115 kbit/s
- Transmission range
  - Passive: up to 3 m
  - Active: up to 30-100 m
  - Simultaneous detection of up to, e.g., 256 tags, scanning of, e.g., 40 tags/s
- Frequency
  - 125 kHz, 13.56 MHz, 433 MHz, 2.4 GHz, 5.8 GHz , others
- Security
  - Application dependent, typically no crypto on RFID device
- Cost
  - Very cheap tags, down to 1€ (passive)
- Availability
  - Many products, many vendors

RFID – Radio Frequency Identification (2)

- Connection set-up time
  - Depends on product/medium access scheme (typ. 2 ms per device)
- Quality of Service
  - none
- Manageability
  - Very simple, same as serial interface
- Special Advantages/Disadvantages
  - Advantage: extremely low cost, large experience, high volume available, no power for passive RFIDs needed, large variety of products, relative speeds up to 300 km/h, broad temp. range
  - Disadvantage: no QoS, simple denial of service, crowded ISM bands, typically one-way (activation/ transmission of ID)

RFID – (3)

- Function
  - Standard: In response to a radio interrogation signal from a reader (base station) the RFID tags transmit their ID
  - Enhanced: additionally data can be sent to the tags, different media access schemes (collision avoidance)
- Features
  - No line-of sight required (compared to, e.g., laser scanners)
  - RFID tags withstand difficult environmental conditions (sunlight, cold, frost, dirt etc.)
  - Products available with read/write memory, smart-card capabilities
- Categories
  - Passive RFID: operating power comes from the reader over the air which is feasible up to distances of 3 m, low price (1€)
  - Active RFID: battery powered, distances up to 100 m

RFID – (4)

- Applications
  - Total asset visibility: tracking of goods during manufacturing, localization of pallets, goods etc.
  - Loyalty cards: customers use RFID tags for payment at, e.g., gas stations, collection of buying patterns
  - Automated toll collection: RFIDs mounted in windshields allow commuters to drive through toll plazas without stopping
  - Others: access control, animal identification, tracking of hazardous material, inventory control, warehouse management, ...

- Local Positioning Systems
  - GPS useless indoors or underground, problematic in cities with high buildings
  - RFID tags transmit signals, receivers estimate the tag location by measuring the signal‘s time of flight

RFID – (5)

- Security
  - Denial-of-Service attacks are always possible
    - Interference of the wireless transmission, shielding of transceivers
  - IDs via manufacturing or one time programming
  - Key exchange via, e.g., RSA possible, encryption via, e.g., AES

- Future Trends
  - RTLS: Real-Time Locating System – big efforts to make total asset visibility come true
  - Integration of RFID technology into the manufacturing, distribution and logistics chain
  - Creation of „electronic manifests“ at item or package level (embedded inexpensive passive RFID tags)
  - 3D tracking of children, patients

ISM band interference

- Many sources of interference
  - Microwave ovens, microwave lighting
  - 802.11, 802.11b, 802.11g, 802.15, …
  - Even analog TV transmission, surveillance
  - Unlicensed metropolitan area networks
  - …
- Levels of interference
  - Physical layer: interference acts like noise
    - Spread spectrum tries to minimize this
    - FEC/interleaving tries to correct
  - MAC layer: algorithms not harmonized
    - E.g., Bluetooth might confuse 802.11

OLD

NEW

© Fusion Lighting, Inc., now used by LG as Plasma Lighting System

Next

- Ch 5 (Schiller): Satellite Systems
- History
- Basics
- Localization
- Handover
- Routing
- Systems

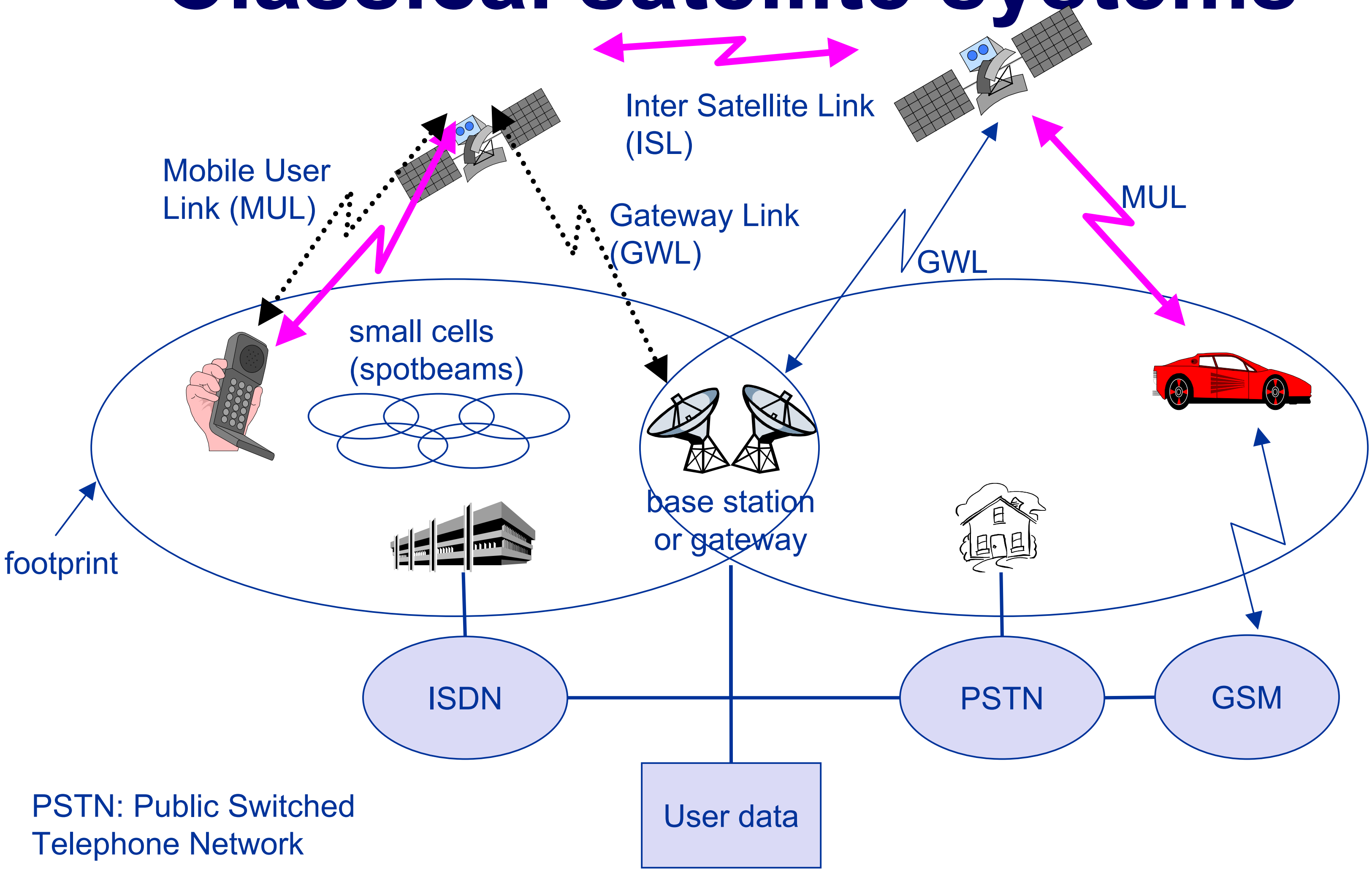
History of satellite communication

- 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 Satellite “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 }
  - 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



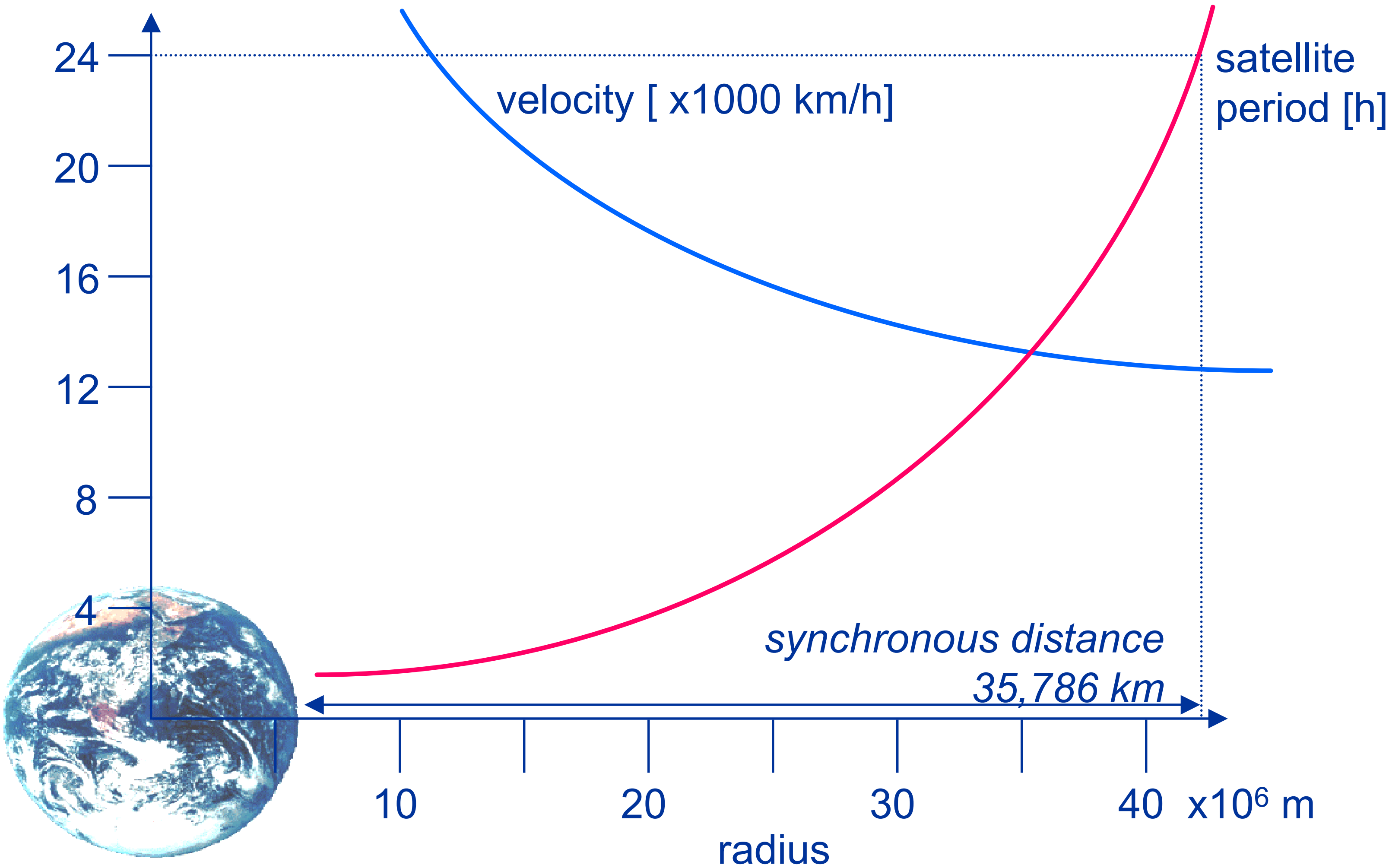
PSTN: Public Switched
Telephone Network

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
  - $F_g = F_c$

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

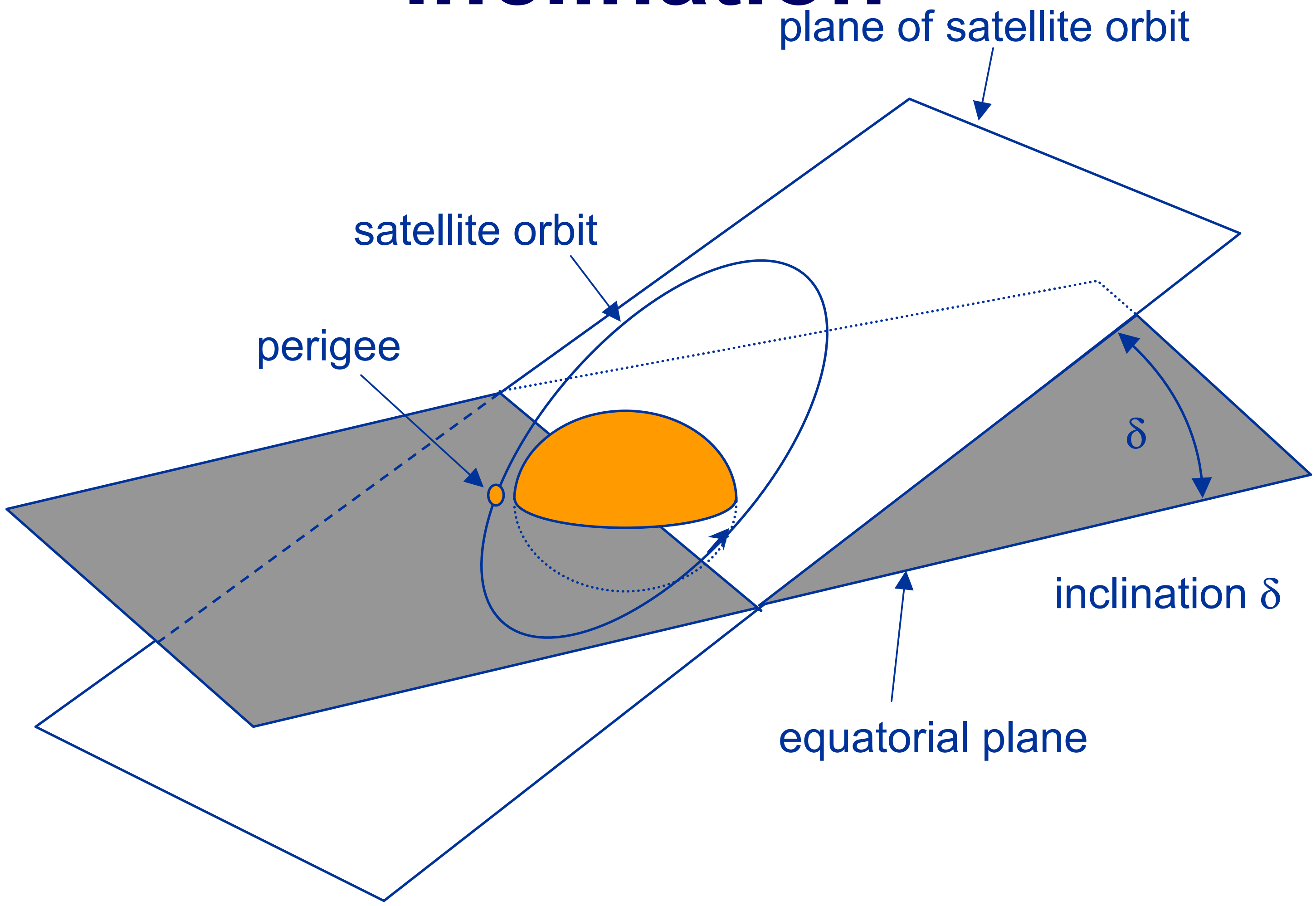
Satellite period and orbits



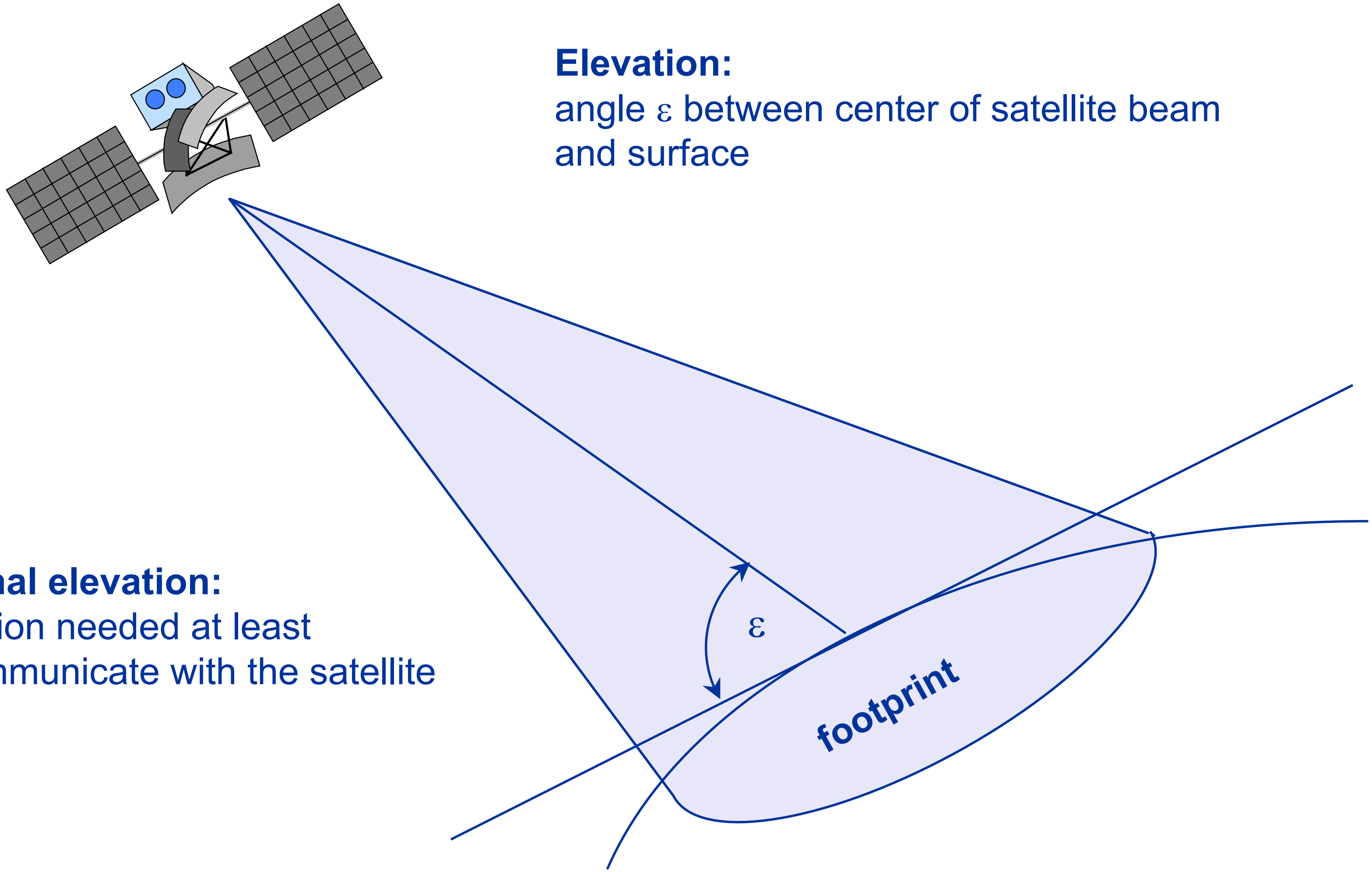
Basics

- 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

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

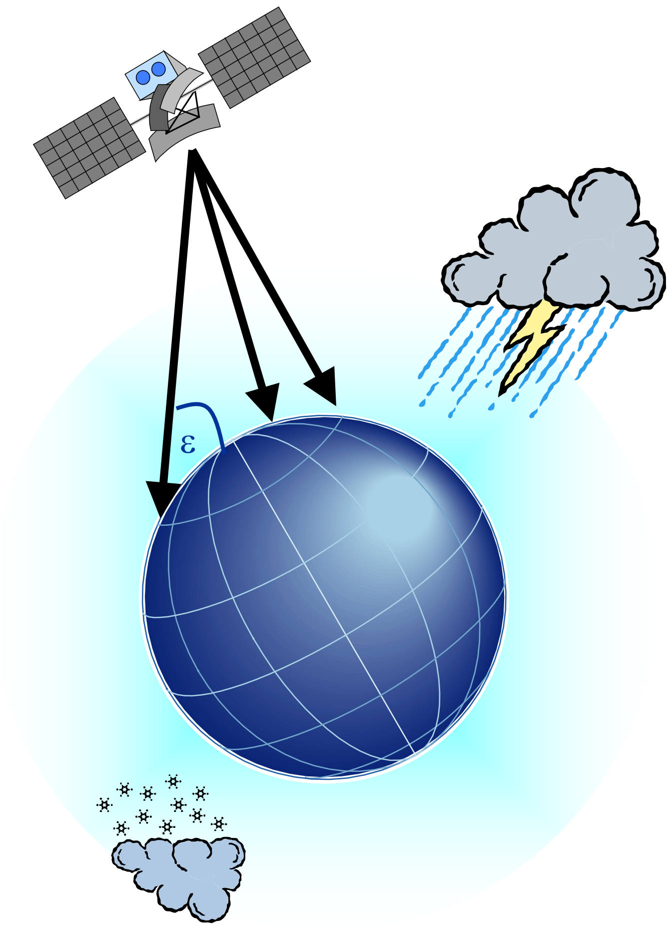
Problems

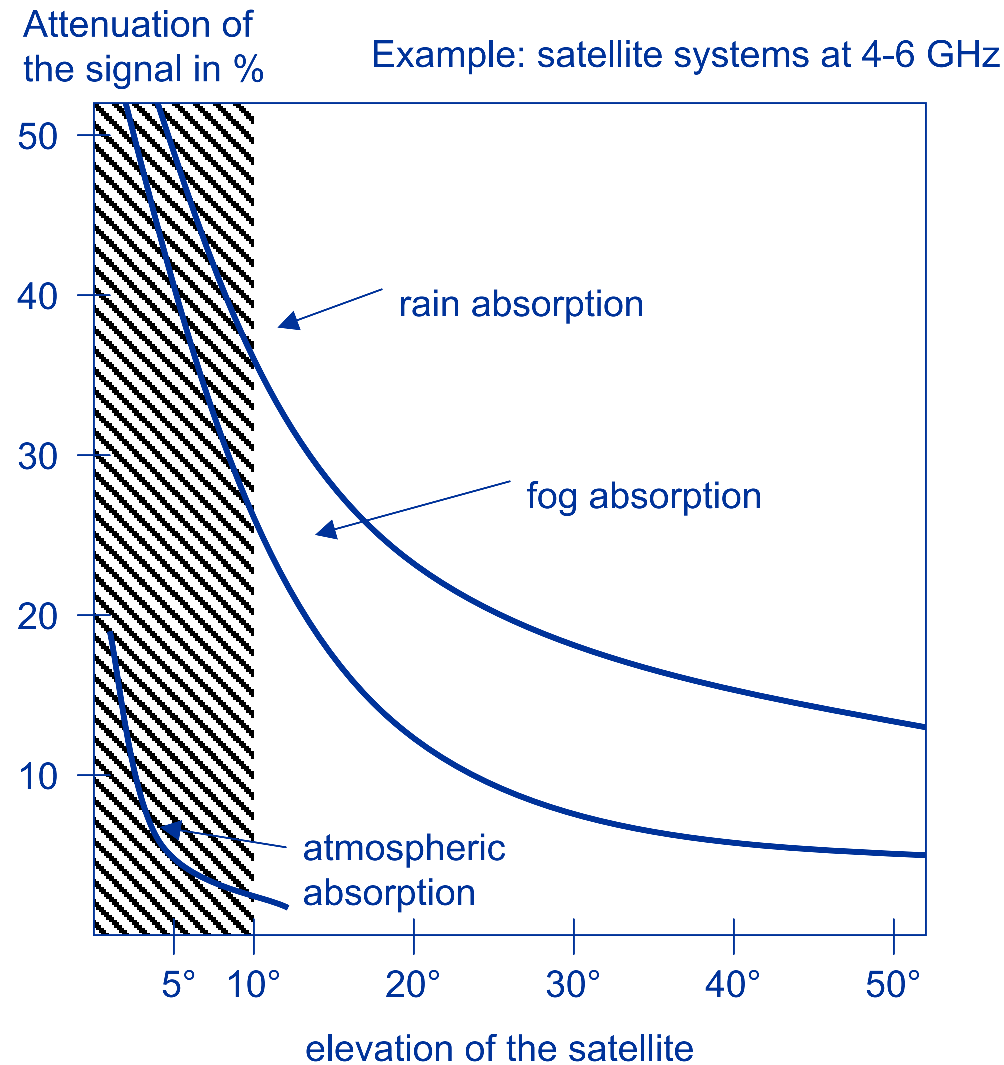
- varying strength of received signal due to multipath propagation
- interruptions due to shadowing of signal (no LOS)

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

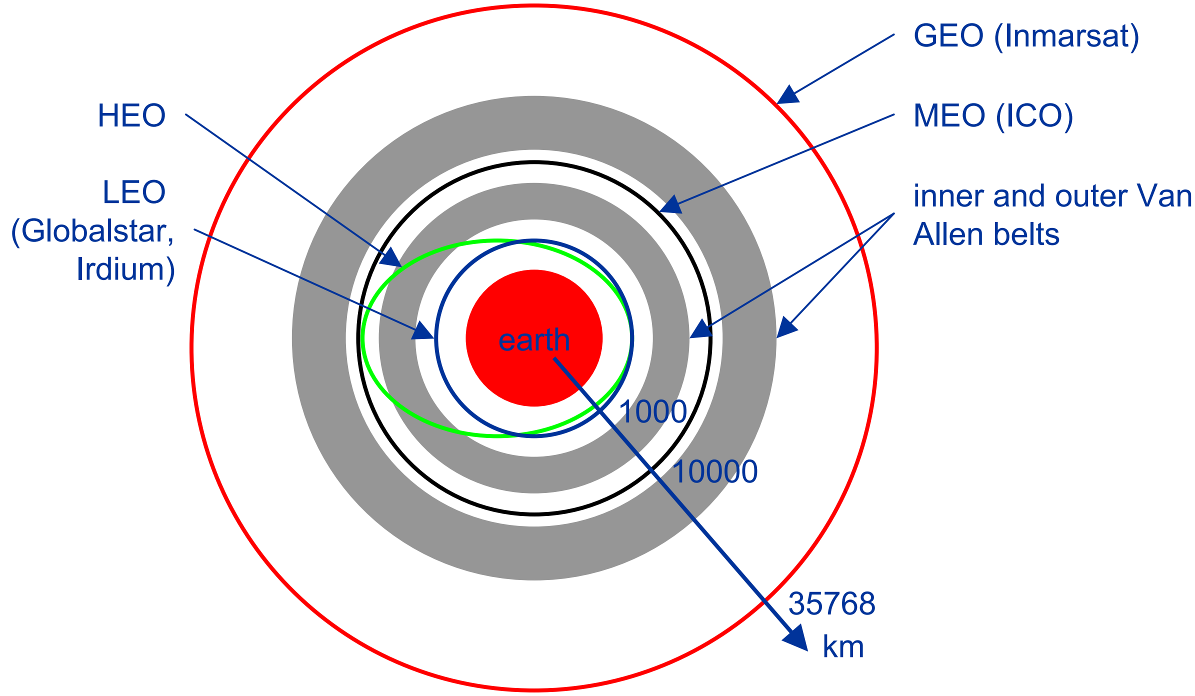




Orbits I

- 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

- 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

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

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$