# CS480: MOBILE NETWORKS

## Satellite Systems

24th January 2017

# Topics Covered

- History of satellite communication
- Applications
- Basics
- GEO
- LEO
- MEO
- Routing
- Localization
- Handover

# History of satellite communication

# History (1)

- Satellite communication began after Second World War
- 1945: Arthur C. Clarke published an essay about “Extra Terrestrial Relays”
- 1957: First satellite SPUTNIK launched by Soviet Union.
  - This shocked the Western world.
- 1960: First reflecting communication satellite ECHO developed by US was in space.
  - Basically a mirror in the sky, enabling communication by reflecting signals.
- 1963: First geostationary satellite SYNCOM followed.
  - Even today, geostationary satellites are the backbone of news broadcasting in the sky.
  - The great advantage is their fixed position in the sky.

# History (2)

- 1965: First commercial geostationary communication satellite INTELSAT I (Early Bird) went into operation
  - In service for 1.5 years, weighed 68kg and offered 240 duplex telephone channels or 1 TV channel.
- 1967: INTELSAT 2 followed
- 1969: INTELSAT 3 followed
  - offered 1,200 telephone channels
- 1976: Three MARISAT satellites for maritime communication
- 1982: First mobile satellite telephone system INMARSAT-A was introduced.
- 1988: First satellite system for mobile phones and data communication INMARSAT-C

# History (3)

- 1993:First digital satellite telephone system INMARSAT-M
  - Devices needed for data communication via geostationary satellites were heavy (several kilograms) and needed a lot of transmit power to achieve decent data rates.
- 1998: Global satellite systems (Iridium and Globalstar) for small mobile phones was introduced
- There are currently almost 200 geostationary satellites in commercial use which shows an impressive growth of satellite communication over the last 30 years.

# Applications

# Applications (1)

Traditionally satellites have been used in following areas:

- Weather forecasting
  - several satellites deliver pictures of the earth using e.g., infra red or visible light.
  - Without the help of satellites, the forecasting of hurricanes would be impossible.
- Radio and TV broadcast satellites
  - Hundreds of radio and TV programs are available via satellite.
- Military satellites
  - One of the earliest applications of satellites was their use for carrying out espionage.
  - Many communication links are managed via satellite because they are much safer from attack by enemies.

# Applications (2)

- Satellites for navigation
  - The global positioning system (GPS) is well-known and available for everyone though was initially used for military purposes.
  - It allows for precise localization worldwide.
  - Almost all ships and aircraft rely on GPS.
  - Many trucks and cars come with installed GPS receivers.
  - The system is also used, e.g., for fleet management of trucks or for vehicle localization in case of theft.

# Applications (3)

In the context of mobile communication, the capabilities of satellites to transmit data is of interest.

- Global telephone backbones
  - One of the first applications of satellites for communication was establishment of international telephone backbones.
  - Instead of using cables, it was sometimes faster to launch a new satellite (aka “big cable in the sky”).
  - Though still being used, there are being replaced by high capacity fiber optical cables across the oceans.
- Connections for remote or developing areas
  - Many places all over the world do not have direct wired connection to the telephone network or the Internet (due to their geographical location).
  - Examples include researchers on Antarctica

# Applications (4)

- Global mobile communication
  - The latest trend for satellites is the support of global mobile data communication.
  - The basic purpose of satellites for mobile communication is not to replace the existing mobile phone networks, but to extend the area coverage.
  - Cellular phone systems, such as GSM do not cover all parts of the country.
  - With the integration of satellite communication, the mobile phone can switch to satellites offering worldwide connectivity to a customer.

# Applications (5)

- Figure 1 shows a classical scenario for satellite systems supporting global mobile communication.
- Depending on its type, each satellite can cover a certain area on the earth with its beam (footprint).
- Within the footprint, communication with satellite is possible for mobiles via a *mobile user link* (MUL).
- For the base station controlling the satellite, and acting as a gateway to other networks, communication is possible via the *gateway link* (GWL).
- Satellites can be able to communicate directly with each other via *inter satellite links* (ISL).

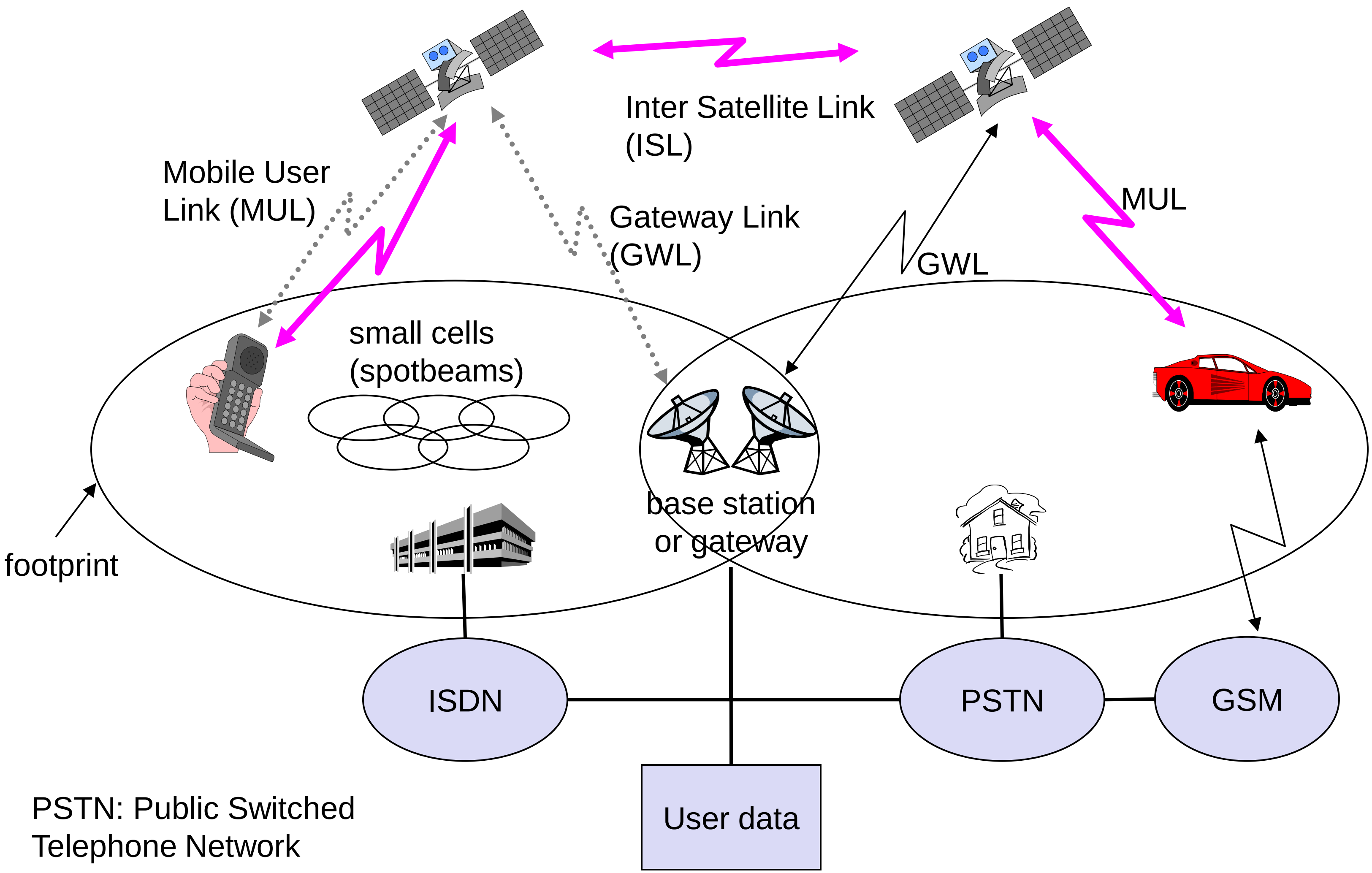



**Figure 1: Typical satellite system for global mobile communications**

# Basics

# Basics (1)

- Satellites orbit around the earth.
- Depending on the application, these orbits can be circular or elliptical.
- Satellites in circular orbits always keep the same distance to the earth's surface following a simple law:
  - The attractive force $F_g$ of the earth due to gravity equals $mg(R/r)^2$
  - The centrifugal force $F_c$ tying to pull the satellite away equals $mrw^2$
- The variables have the following meaning:

m is the mass of the satellite;

R is the radius of the earth with $R$ = 6,370 km;

$r$ is the distance of the satellite to the centre of the earth;

$g$ is the acceleration of gravity with $g$ =9.81 m/s$^2$;

$w$ is the angular velocity with $w=2\pi f$, $f$ is the frequency of the rotation.

# Basics (2)

- To keep the satellite in a stable orbit, the following equation must hold:

  $F_g = F_c$, i.e., both forces must be equal

- Solving the equation for the distance r of the satellite to the center of the earth results in

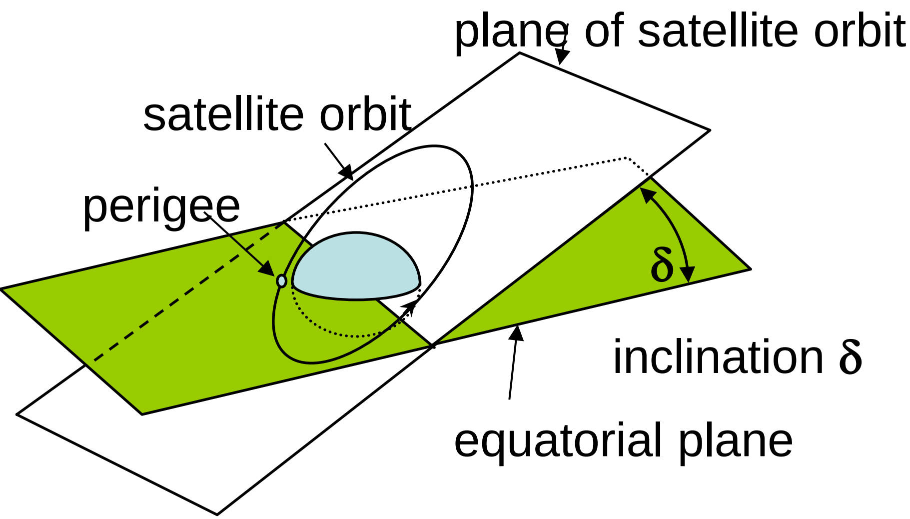
  $\boldsymbol{r = (gR^2/(2\pi f)^2)^{1/3}}$

- The distance of a satellite to the earth's surface depends on its rotation frequency.
- When the satellite period is 24 hours, the distance from the surface of the earth is 35,786 km.
- This is the case for geostationary satellite if it is placed above the equator.

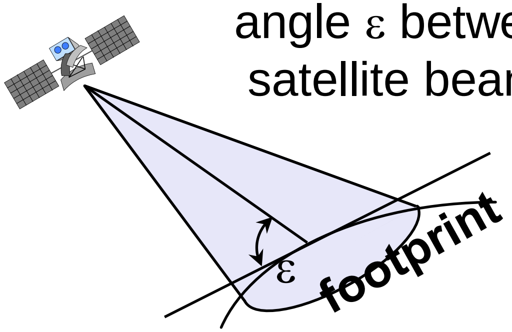
# Basics (3)

Important parameters in satellite communication are:

- Inclination angle (δ)
  - This is the angle between the equatorial plane and the plane described by the satellite orbit (see Figure 2 left).
  - δ=0 means the satellite is exactly above the equator.
- Elevation angle (ε)
  - This is the angle between the center of the satellite beam and the plane tangential to the earth's surface (see Figure 2 right).
- A footprint is the area on earth where the signals of the satellite are received.




**Elevation:**
angle ε between center of satellite beam and surface




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

**Figure 2: Left: Inclination angle of a satellite, and right: elevation angle of a satellite.**

# Basics (4)

Four different types of orbits can be identified as shown in Figure 3:

- Geostationary (or geosynchronous) earth orbit (GEO):
  - GEO satellites have a distance of almost 36,000 km to the earth.
  - Examples are almost all TV and radio broadcast satellites, many weather satellites and satellites operating as backbones for the telephone network.
- Medium earth orbit (MEO)
  - MEOs operate at a distance of about 5,000-12,000 km.
  - Up to now there have not been many satellites in this class,
  - But some upcoming systems (e.g., Intermediate Circular Orbits (ICO)) use this class for various reasons
- Low earth orbit (LEO)
  - While some time ago LEO satellites were mainly used for espionage, several of the new satellite systems now rely on this class using altitudes of 500-1,500km.

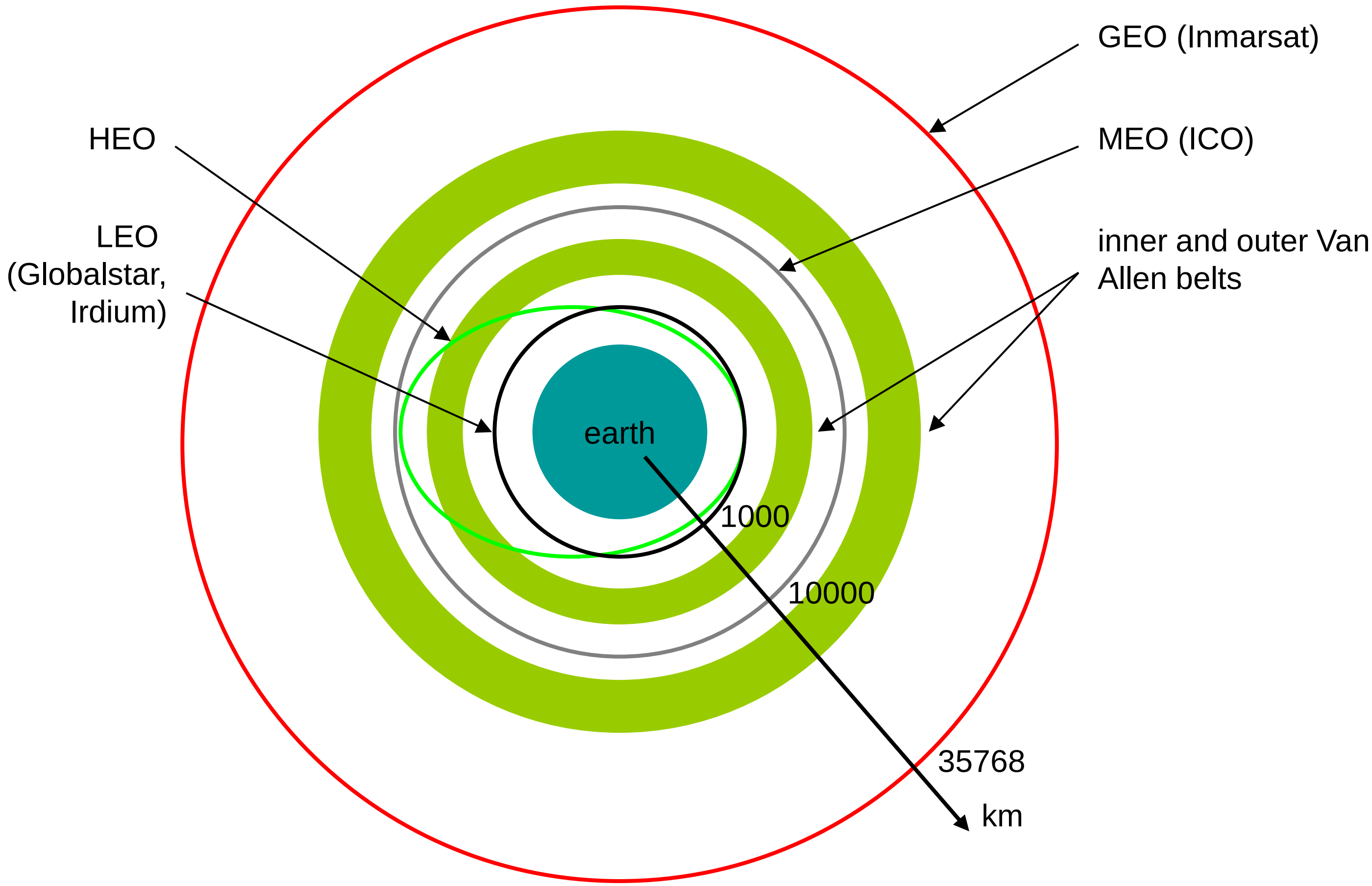



**Figure 3: Different types of satellite orbits**

# Basics (6)

- Highly elliptical orbit (HEO)
  - This class comprises all satellites with non-circular orbits.
  - Currently, only a few commercial communication systems using satellites with elliptical orbits are planned.
  - These systems have their perigee over large cities to improve communication quality.
- The Van Allen radiation belts
  - These are belts consisting of ionized particles, at heights of about 2,000-6,000km (inner Van Allen belt) and about 15,000-30,000km (outer Van Allen belt) respectively
  - These make satellite communication very difficult in these orbits.

# GEO

# GEO (1)

- If a satellite should appear fixed in the sky, it requires a period of 24 hours.
- Using the equation for the distance between earth and satellite $r = (gR^2/(2\pi f)^2)^{1/3}$ and the period of 24 hours, $f$=1/24h, the resulting distance is 35,786 km.
  - The orbit must have an inclination of 0 degrees
- Advantages
  - Three GEO satellites are enough for a complete coverage of almost any spot on earth
  - Senders and receivers can use fixed antenna positions, no adjusting is needed
  - GEOs are ideal for TV and radio broadcasting.
  - Lifetime expectations for GEOs are rather high, at about 15 years

# GEO (2)

  - GEOs typically do not need a handover due to a large footprint
  - GEOs do not exhibit any Doppler shift because the relative movement is zero
- Disadvantages
  - Northern or southern regions of the earth have more problems receiving these satellites due to the low elevation above a latitude of 60$^o$, larger antennas are needed in this case
  - Shading of signals in cities due to high buildings and the low elevation further away from the equator limit transmission quality
  - The transmit power needed is relatively high which causes problems for battery powered devices
  - These satellites cannot be used for small mobile phones
  - The biggest problem for voice and data communication is the high latency of over 0.25 s one-way; many retransmission schemes known from fixed networks fail

# GEO (3)

- Due to large footprint, either frequencies cannot be reused or the GEO satellites needs special antennas focusing on smaller footprint
- Transferring a GEO into orbit is very expensive

# LEO

# LEO (1)

- As LEO circulate on a lower orbit, it is obvious that they exhibit a much shorter period (typical periods are 95 to 120 minutes)
- LEO systems try to ensure a high elevation for every spot on earth to provide a high quality communication link
- Each LEO satellite will only be visible from the earth for around ten minutes
- Advantages
  - Using advanced compression schemes, transmission rates of about 2,400 bit/s can be enough for voice communication.
    - LEOs even provide this bandwidth for mobile terminals with omni-directional antennas using low transmit power in the range of 1W

# LEO (2)

- The delay of packets delivered via a LEO is relatively low (approx 10 ms) which is comparable to long-distance wired connections (about 5-10 ms)
- Smaller footprints of LEOs allow for better frequency reuse, similar to the concepts used for cellular networks
- LEOs can provide a much higher elevation in polar regions and so better global coverage

- Disadvantages
  - The biggest problem is the need for many satellites if global coverage is to be reached.
    - Several LEO concepts involve 50-200 or more satellites in orbit.
  - The short time of visibility with a high elevation requires additional mechanisms for connection handover between different satellites
  - The high number of satellites combined with the fast movements results in a high complexity of the whole satellite system

# LEO (3)

- One general problem of LEOs is the short lifetime of about 5-8 years due to atmospheric drag and radiation from the inner Van Allen belt.
  - Assuming 48 satellites and a lifetime of 8 years (expected for Globalstar), a new satellite would be needed every two months
- The need for routing of data packets from satellite to satellite if a user wants to communicate around the world.

MEO

# MEO (1)

- MEOs can be positioned somewhere between LEOs and GEOs, both in terms of their orbit and due to their advantages and disadvantages
- Advantages
  - Using orbits around 10,000 kms, the system only requires a dozen satellites which is more than a GEO system, but much less than a LEO system
  - These satellites move more slowly relative to the earth's rotation allowing a simpler system design (satellite periods are ~ 6 hrs)
  - Depending on inclination, MEOs can cover larger populations, so requiring fewer handovers
- Disadvantages
  - Due to larger distance to earth, delay increases to ~ 70-80 ms.
  - These satellites need higher transmit power and special antennas for smaller footprints

# Routing

# Routing (1)

- A satellite system together with gateways and fixed terrestrial networks (shown in Figure 1) has to route data transmissions from one user to another as any other network does
- Routing in the fixed segment (on earth) is achieved as usual, while two different solutions exist for the satellite network in space
- If satellites offer ISLs, traffic can be routed between the satellites
  - Assume two users of a satellite network exchange data.
  - If the satellite system supports ISLs, one user sends data up to a satellite and the satellite forwards it to the one responsible for the receiver via other satellites.

# Routing (2)

- The last satellite now sends data down to earth. One uplink and one downlink per direction is needed.
- Routing within satellite network reduces the number of gateways needed on earth

- If not, all traffic is relayed to earth, routed there, and relayed back to a satellite
  - Here the user also sends data up to a satellite, but this satellite forwards data to gateway on earth
  - Routing takes place in fixed networks until another gateway is reached which is responsible for the satellite above the receiver
  - Data is sent up to the satellite which forwards it down to a receiver.
  - This solution requires two uplinks and two downlinks

# Localization

# Localization

- Localization of users in satellite networks is similar to that of terrestrial cellular networks
- One additional problem arises from the fact that the “base stations”, i.e., the satellites, move as well
- The gateways of a satellite network maintain several registers
  - Home location register (HLR): this stores all static information about a user as well as his or her current location
  - Visitor location register (VLR): this stores the last known location of a mobile user
  - Satellite user mapping register (SUMR): this stores the current position of satellites and a mapping of each user to the current satellite through which communication with a user is possible

# Handover

# Handover (1)

- An important topic in satellite systems using MEOs and in particular LEOs
- Imagine a cellular mobile phone network with fast moving base stations.
  - This is exactly what such satellite systems are – each satellite represents a base station for a mobile phone
- Compared to terrestrial mobile phone networks, additional instances of handover can be necessary due to movement of satellites
- Intra-satellite handover
  - A user might move from one spot beam of a satellite to another of the same satellite.
  - Using special antennas, a satellite can create several spot beams within its footprint.
  - The same effect may be caused by the movement of the satellite

# Handover (2)

- Inter-satellite handover
  - If a user leaves the footprint of a satellite or if the satellite moves away, a handover to the next satellite takes place.
  - This might be a hard handover switching at one moment or a soft handover using both satellites at the same time.
  - Inter-satellite handover can also take place between satellites if they support ISLs
- Gateway handover
  - While the mobile user and satellite might still have good contact, the satellite might move away from the current gateway.
  - The satellite has to connect to another gateway
- Inter-system handover
  - This type of handover concerns different systems.
  - Typically, satellite systems are used in remote areas if no other network is available.
  - As soon as traditional cellular networks are available, users might switch to them since it is cheaper and offers lower latency