COMP4310/6310 Wireless Mobile Computing

Satellite Systems
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 (e.g., GSM or AMPS)
Features

• What modulation scheme we should use at the physical layer?
  - BPSK?
  - QPSK?
  - 256QAM?

• What MAC protocol should be a the MAC layer.
  - TDMA/FDMA/SDMA/CDMA ?
  - ALOHA/CSMA/802.11DCF ?
Typical satellite systems

- **Inter Satellite Link (ISL)**
- **Mobile User Link (MUL)**
- **Gateway Link (GWL)**
- **Small cells (spotbeams)**
- **Base station or gateway**
- **Footprint**

**Networks**
- **PSTN**: Public Switched Telephone Network
- **ISDN**
- **GSM**

**User data**

PSTN: Public Switched Telephone Network
Satellite period and orbits

- Radius
- Velocity [x1000 km/h]
- Synchronous distance 35,786 km
- Satellite period [h]
Atmospheric attenuation

Example: satellite systems at 4-6 GHz

Attenuation of the signal in %

- rain absorption
- fog absorption
- atmospheric absorption

elevation of the satellite
the original vision

- 1945 Arthur C Clark envisaged “extraterrestrial relays”
- 3 satellites
- 36,000km high
- equatorial orbit
- see the entire planet
Orbits

- LEO (Globalstar, Irdium)
- HEO
- MEO (ICO)
- GEO (Inmarsat)

Distances:
- 1000 km
- 10000 km
- 35768 km
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, typically used for radio and TV transmission
→ VSAT - broadband Internet access in remote locations
LEO

- Low Earth Orbit
- High orbit speed
- Many satellites
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)
  - Globalstar (start 1999, 48 satellites)
MEO

• Medium Earth Orbit
• New generation
• About 12 satellites
• Voice and mobile
• ICO (Odyssey), Orbcomm, Ellipso
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:
  - GPS 24 satellites (6 planes, 4 satellites per plane)
  - ICO (Intermediate Circular Orbit, Inmarsat) start ca. 2000
## Overview of LEO/MEO systems

<table>
<thead>
<tr>
<th></th>
<th>Iridium</th>
<th>Globalstar</th>
<th>ICO</th>
<th>Teledesic</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong># satellites</strong></td>
<td>66 + 6</td>
<td>48 + 4</td>
<td>10 + 2</td>
<td>288</td>
</tr>
<tr>
<td><strong>altitude (km)</strong></td>
<td>780</td>
<td>1414</td>
<td>10390</td>
<td>ca.700</td>
</tr>
<tr>
<td><strong>coverage</strong></td>
<td>global</td>
<td>±70° latitude</td>
<td>global</td>
<td>global</td>
</tr>
<tr>
<td><strong>min. elevation</strong></td>
<td>8°</td>
<td>20°</td>
<td>20°</td>
<td>40°</td>
</tr>
<tr>
<td><strong>frequencies [GHz (circa)]</strong></td>
<td>1.6 MS ↑</td>
<td>1.6 MS ↑</td>
<td>2 MS ↑</td>
<td>19 ↓</td>
</tr>
<tr>
<td></td>
<td>29.2 ↑</td>
<td>2.5 MS ↓</td>
<td>2.2 MS ↓</td>
<td>28.8 ↑</td>
</tr>
<tr>
<td></td>
<td>19.5 ↓</td>
<td>5.1 ↑</td>
<td>5.2 ↑</td>
<td>62 ISL</td>
</tr>
<tr>
<td></td>
<td>23.3 ISL</td>
<td>6.9 ↓</td>
<td>7 ↓</td>
<td></td>
</tr>
<tr>
<td><strong>access method</strong></td>
<td>FDMA/TDMA</td>
<td>CDMA</td>
<td>FDMA/TDMA</td>
<td>FDMA/TDMA</td>
</tr>
<tr>
<td><strong>ISL</strong></td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td><strong>bit rate</strong></td>
<td>2.4 kbit/s</td>
<td>9.6 kbit/s</td>
<td>4.8 kbit/s</td>
<td>64 Mbit/s ↓</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2/64 Mbit/s ↑</td>
</tr>
<tr>
<td><strong># channels</strong></td>
<td>4000</td>
<td>2700</td>
<td>4500</td>
<td>2500</td>
</tr>
<tr>
<td><strong>Lifetime [years]</strong></td>
<td>5-8</td>
<td>7.5</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td><strong>cost estimation</strong></td>
<td>4.4 B$</td>
<td>2.9 B$</td>
<td>4.5 B$</td>
<td>9 B$</td>
</tr>
</tbody>
</table>
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.
VSAT

- Very Small Aperture Terminal
- fixed antenna (dish / aperture)
- 0.65m to 2.4m diameter antenna
- VSAT network includes a hub
- Hub has a large dish ~6m +
- All communications to and from VSAT back to hub (no meshing)
- Suits asymmetric networks - more traffic from hub, less from VSAT
- Data, video, audio

Fixed - not Mobile!
GEO- a renewed interest in VSAT

- distance & geography independent
- good for broadcast, multicast
- IP friendly
- DTH or Community distribution
- rapid deployment
- min expansion costs
- high reliability
- data, video, audio
## Service Offering from VSAT-Systems (Feb. 2007)

<table>
<thead>
<tr>
<th>Service Level*</th>
<th>Throughput Allowance**</th>
<th>CIR*</th>
<th>Monthly Pricing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5Mbps/200Kbps</td>
<td>500MB</td>
<td>1.02Mbps/ 96Kbps</td>
<td>$99.00</td>
</tr>
<tr>
<td>1.5Mbps/384Kbps</td>
<td>1.0GB</td>
<td>1.02Mbps/ 128Kbps</td>
<td>$149.00</td>
</tr>
<tr>
<td>2.04Mbps/512Kbps</td>
<td>2.0GB</td>
<td>1.02Mbps/ 256Kbps</td>
<td>$199.00</td>
</tr>
<tr>
<td>2.04Mbps/640Kbps</td>
<td>3.0GB</td>
<td>1.5Mbps/ 384Kbps</td>
<td>$249.00</td>
</tr>
<tr>
<td>2.50Mbps/786Kbps</td>
<td>5.0GB</td>
<td>1.5Mbps/ 512Kbps</td>
<td>$399.00</td>
</tr>
<tr>
<td>2.5Mbps/1.02Mbps</td>
<td>7.0GB</td>
<td>2.04Mbps/ 768Kbps</td>
<td>$499.00</td>
</tr>
<tr>
<td>3.07Mbps/1.5Mbps</td>
<td>15.0GB</td>
<td>2.04Mbps/ 1.02Mbps</td>
<td>$999.00</td>
</tr>
</tbody>
</table>

* You can expect the ability to receive at least 90% of the stated CIR speeds 90% of the time, if not more!
Iridium

- Number of Satellites: (66 Active, 6 In-Orbit Spares)
- Geometry: 6 planes
  - Plane 1: 12 satellites, Plane 2: 15 satellites, Plane 3: 12 satellites, Plane 4: 12 satellites, Plane 5: 16 satellites, Plane 6: 17 satellites,
- Orbit LEO - 780 km (470 miles) circular at 86.4 deg.
- Inclination Orbit Period: 100.5 minutes
- Coverage: Global
- Initiation of Operations: November 1998
- Types of Services: Voice and paging, (Proposed: data, fax)
- Voice Transmission Rate (bps): 2400
- (Proposed) Data Rate (bps): 2400
- On-board processing: Yes
- Mobile downlink frequencies (MHz): 1610-1626.5 (L-Band)
- Mobile uplink frequencies (MHz): 1616-1626.5 (L-Band)
- Modulation: FDMA/TDMA
- Voice circuit capacity / satellite: 1100
Iridium (cont)

- Intersatellite crosslinks - 10Mbps
- Four links for each satellite:
  - 2 fore and aft for neighbors in the same orbital plane and
  - 2 on the sides for neighboring satellites
- No links at the “seam”

- Orbit is pole-to-pole with period of about 100 minutes
- Four gateways on the ground to relay the calls.

- Station-to-station calls do not go through gateways

- "Iridium will succeed because every time we estimated the growth of cellular phones, we were LOW by a factor of four" - Bary Bertiger of Motorola, system inventor.
Iridium satellite

**Sketch of the Iridium satellite design**

- **Communication antenna (3):**
  - 86 cm wide
  - 186 cm high
  - 4 cm thick
  - 106 radiating elements
  - 16 beams per antenna
  - 48 beams juxtaposed
Iridium communication
Global Star

- Number of Satellites: 48 (4 spares) (12 satellites lost by Russians)
- 8 planes of 6 satellites each
- Orbit: LEO - 52 deg. Inclination - no coverage at the poles
- Bent pipe design: no global coverage
- Initiation of Operations: 1999 - 2002 (bankrupt), bought for $43M now active
Global Star Coverage
Globalstar satellite in its on-orbit configuration
Globalstar
Teledesic

- Number of Satellites: 288 (down from 840)
- Active Geometry: 12 planes, 24 satellites each
- Orbit: LEO - 1375 km (828 miles) circular, 85 deg. Inclination
- Orbit Period: 113.2 minutes
- Coverage: Global
- Initiation of Operations: halted
- Types of Services: Broadband Data and Voice
- Uplink Data Rate: 16kbps to 2Mbps (down from 100Mbps)
- Downlink Data Rate: 16kbps to 64Mbps (down from 720Mbps)
- On-board processing: Yes
- Mobile uplink frequencies: 28.6-29.1 GHz (Ka-Band)
- Mobile downlink frequencies: 18.8-19.3 GHz (Ka-Band)
- Multiple access scheme: FDMA/TDMA
- Channels / Satellite: 100,000 at 16kbps
ICO

- Number of Satellites: 12 (10 Active)
- Geometry: 2 planes, 6 satellites each
- Orbit: MEO - 10,390 km (6,259 miles) circular at 45 degrees inclination
- Orbit Period: 361 minutes
- Coverage: Global
- Initiation of Operations: ?
- Only one satellite up, the rest in storage
- Types of Services: voice, data, fax, short message service
- Voice Transmission Rate (bps): 4800
- Data Rate (bps): 2400-9600
- On-board processing: Yes
- Mobile downlink frequencies (MHz): 1980 - 2010
- Mobile uplink frequencies (MHz): 2170-2200
- Modulation: TDMA
- Maximum earth-space link one-way propagation delay: 48 ms
- Minimum mobile terminal elevation angle: 10 degrees
- Voice circuit capacity / satellite: 4500
ICO