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Overview of Satellite Communications

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History of Satellite Communications

- **Origins**
  - 1947 Arthur C Clarke proposes Geostationary Earth Orbit Satellites
  - 1957 Russians put Sputnik in low earth orbit
  - 1962-3 AT&T experiments with Telstar I and II MEO satellites
  - 1965 - April 6: Early Bird (aka Intelsat I) begins era of commercial GEO satellite communications

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Era of Expansion 1970 - 1980

- **GEO satellite services** spread rapidly
  - Intelsat: International telephone service over three ocean regions, some data and video traffic
  - Regional: Europe, Canada, Indonesia - telephone and data service over wide areas
  - Domestic: USA, Italy, Japan - Video distribution, data links, telephone traffic
  - “Live by satellite” becomes the norm

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Growth of GEO Satellites

1965	Early Bird	34 kg	240 telephone circuits
1968	Intelsat III	152 kg	1500 circuits
1986	Intelsat VI	1,800 kg	33,000 circuits
2000	Large GEO	3000 kg	8 - 15 kW power 1,200 kg payload

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Then Came Optical Fibers

- **Telephone links via GEO satellites**:
  - A long way to travel (80,000 km each way)
  - Round trip delay is 500 ms - very noticeable

- **Optical fibers**, when available, are
  - Much cheaper to operate than satellites
  - Have indefinite lifetime - don't have to be relaunched
  - Have huge capacity - 2.7 Gbps per fiber is common
  - Guarantee lower bit error rate

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GEO Satellite Applications

- **Broadcasting** - mainly TV at present
  - Directv, PrimeStar, etc
- **Point to Multi-point** communications
  - VSAT, Video distribution for Cable TV
- **Mobile Services**
  - American Mobile Satellite, Inmarsat

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Satellite Communications 1990 - 2000

- What do GEO satellites do best?
- **BROADCASTING!**
- Video services by satellite earned $17 Billion in 1998
  - Wall Street Journal called Direct Broadcast Satellite TV the Greatest Technology Development of the Century

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Satellite Communications 2000 +

- **Low Earth Orbit (LEO)** Satellite Systems are here
  - Orbcomm (1998), Iridium (1999), GlobalStar (2000), ICO-Global (2002)
  - More systems are being developed
  - Little LEO: Data relay, vhf and uhf
  - Big LEO: Voice and Data, like cellular telephone
    L and S bands

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Satellite Navigation: GPS and GLONASS

- **GPS** is a medium earth orbit (MEO) satellite system
  - GPS satellites broadcast pulse trains with very accurate time signals
  - A receiver able to "see" four GPS satellites can calculate its position within 30 m anywhere in world
  - 24 satellites in clusters of four, 12 hour orbital period
- "You never need be lost again"
  - Every automobile and cellular phone will eventually have a GPS location read-out

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The Challenge

- **High speed two way Internet Access**

  - Two way fixed satellite service to home terminal at Megabit per second rates

  - Two way links to Mobiles - but at what speed?

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GEO Satellites 2000+

- **Big, Heavy, Powerful, and Expensive**
- Circular orbit in equatorial plane
  - 35,426 km altitude
  - Appears stationary at a point in the sky
    - we can use fixed earth station antennas
- **Weight**: 3,000 kg on orbit.
  - Half weight is fuel
- 15 year lifetime - if sufficient station keeping fuel

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GEO Satellites 2000+

- **Power**
  - 8 - 15 kW from 50 m^2 solar cells, 25 kW predicted
  - Up to 100 C, Ku and/or Ka band transponders
- **Cost**
  - Typical cost: $200M to build and launch to GEO
  - Offer lowest cost per bit transmitted
- Hundreds in orbit - every 2^o or 3^o around GEO

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LEO Satellites in year 2000

- Several new systems are just starting service
  - Circular or inclined orbit with < 1400 km altitude
  - Satellite travels across sky from horizon to horizon in 5 - 15 minutes
  - Earth stations must track satellite or have omni-directional antennas
  - Constellation of satellites is needed for continuous communication

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LEO Satellites

- Little LEO example: **Orbcomm**
  - Uses vhf and uhf bands for data relay
  - Short messages (1024 bits typical)
  - Small, lightweight satellite - lower cost, easy to launch
  - Satellite has low capacity - maximum eight channels
  - High cost per bit transmitted
  - Optimum use is for high value bits:
    HELP!   I've been highjacked! Come and rescue me!

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LEO Satellites

- Big LEO example: **Iridium**
  - Constellation of 66 satellites using 1.6 GHz band
  - Two satellites always visible
  - Six inter-satellite links from each satellite (22 GHz)
  - Worldwide voice and data links with cellular phone
  - All digital, compressed voice, FDMA-TDMA and multiple antenna beams (48)
  - Capacity is 1,100 circuits per satellite
  - System cost $5 billion
  - Currently behind projections with customer enrollments

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LEO Satellites

- Big LEO example: **Globalstar**
  - Constellation of 48 satellites using 1.6 and 2.4 GHz bands
  - Two satellites nearly always visible
  - No inter-satellite links
  - Regional voice and data links with cellular phone
  - All digital, compressed voice at 8 kbps using CDMA and multiple antenna beams (16)
  - Capacity is 2,400 circuits per satellite
  - System cost $2.5 billion
  - Call cost comparable to cellular telephone

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LEO Satellites

- Next generation LEO example: **Teledesic**
  - Constellation of 288 satellites using Ka bands (20 - 30 GHz)
  - Many satellites visible
  - Global voice and data links with small fixed terminals
  - 64 beam multiple beam antenna on spacecraft
  - Capacity per satellite is 13.3 Gbps
  - System cost estimated at $9.2 billion (may be higher)
  - Creates equivalent of fiber optic cable network above earth's surface

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The big challenge: Spectrum

- LEO satellites need lower RF frequencies
  - Omni-directional antennas on handsets have low gain - typically $G = 0$ db $= 1$
  - Flux density F in W/m^2 at the earth's surface in any beam is independent of frequency
  - Received power is F x A watts , where A is effective area of antenna in m^2
  - For an omni-directional antenna $A = G \lambda^2 / 4 \pi = \lambda^2 / 4 \pi$
  - At 450 MHz, $A = 353$ cm^2, at 20 GHz, $A = 0.18$ cm^2
  - Difference is 33 dB - so don't use 20 GHz with an omni!

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Current Trends in Satellite Communications

- Bigger, heavier, GEO satellites with multiple roles
- More direct broadcast TV and Radio satellites
- Expansion into Ka, Q, V bands (20/30, 40/50 GHz)
- Massive growth in data services fueled by Internet
- More mobile services
  - May be broadcast services rather than point to point
  - Will Iridium and Teledesic survive?

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Never say Never

- Boston Newspaper Editorial, 1879
  - “All educated individuals must realize that the transmission of the human voice on a wire is impossible, and even if it were, would be of no practical value whatsoever.”
  - Alexander Graham Bell invented the telephone in 1876

- Today’s Goal: Universal Personal Communications
  - In twenty years, people will be able to cheaply transmit and receive voice, data, and video images from a handheld terminal anywhere in the world. (Brian Woerner, MPRG)

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The Future for Satellite Communications

- **Growth requires new frequency bands**
- Propagation through rain and clouds becomes a problem as RF frequencies is increased
  - C-band (6/4 GHz) — Rain has little impact
99.99% availability is possible
  - Ku-band (10-12 GHz) — Link margin of $\geq$ 3 dB needed
for 99.8% availability
  - Ka-band (20 - 30 GHz) — Link margin of $\geq$ 6 dB needed
for 99.6% availability

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The Future for Satellite Communications

- **Low cost phased array antennas** for mobiles are needed
  - Mobile systems are limited by use of omni-directional antennas
  - A self-phasing self-steering phased array antenna with 6 dB gain can quadruple the capacity of a system
  - directional antennas allow frequency re-use

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The Future for Satellite Communications

- **Propagation research** is needed on atmospheric effects
- Slant path propagation at Ka band has been investigated since 1975
  - ATS-6, Comstar, Olympus, ACTS satellites had Ka band beacons for propagation measurements
  - Ka-band effects are well understood
  - Measurements are needed at 37-39 GHz (Q-band) and 47-49 GHz (V-band)
  - Italsat has 40 and 50 GHz beacons, but is located at 15 ^{o} E

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The Future for Satellite Communications

- Propagation research is needed on the effect of attenuation by foliage and by buildings
  - Important for mobile satellite communications because satellite may be hidden by trees
  - When new frequencies are allocated for new services, the propagation effects need to be known
  - Propagation into and out of buildings is a hot topic

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The Future for Satellite Communications

- **Hardware**
  - Lower cost hardware needed for Ka, Q, V bands
  - Large volume of DBS-TV hardware has lowered costs in Ku-band
- **Optical Communications** with satellites
  - Always just out of reach?
  - Good for inter-satellite links, tough for earth-space links
- **Protocols** for Satellite Networks
  - Inter-operability with ATM, TCP-IP is important

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The Future for Satellite Communications

- **The future looks bright**
- Expected revenues from all Satellite Communications services should reach $75 billion by 2005
- Satellite Direct to the Home Broadcasting and Internet services appear to be the major drivers

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The Future for Satellite Communications

- Satellite communications is the only activity in space that has ever returned substantial revenues

  - "If you could launch grains of sand into space and bring them back as grains of gold, it would be uneconomic"
    (David Thompson, CEO, Orbital Sciences, 1990)

  - "If you can think of a signal to broadcast from a satellite that five million people will want to buy, you can become very wealthy"
    (Tim Pratt, Virginia Tech, 1999)

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