Satellites and the Next Generation Internet

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Galactic Information Infrastructure

"We now can at last create a planetary information network that transmits messages and images with the speed of light from the largest city to the smallest village on every continent. … From these connections, we will derive robust and sustainable economic progress, strong democracies, better solutions to global and local environmental challenges, [and] improved health care. … Digital communications technology, fiber optics, and *new high capacity satellite systems* are transforming telecommunications."

Vice President Al Gore, ITU Development Conference, Buenos Aires, March 1994

Presentation Outline

- The Satellite Challenge
  - Regulatory
  - Economic
  - Technical
- Satellite and the Internet
- Summary and Conclusions

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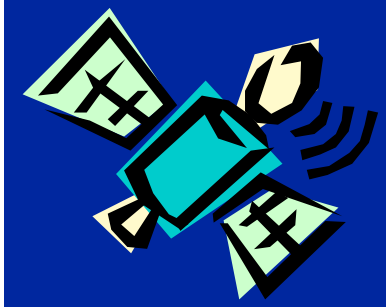
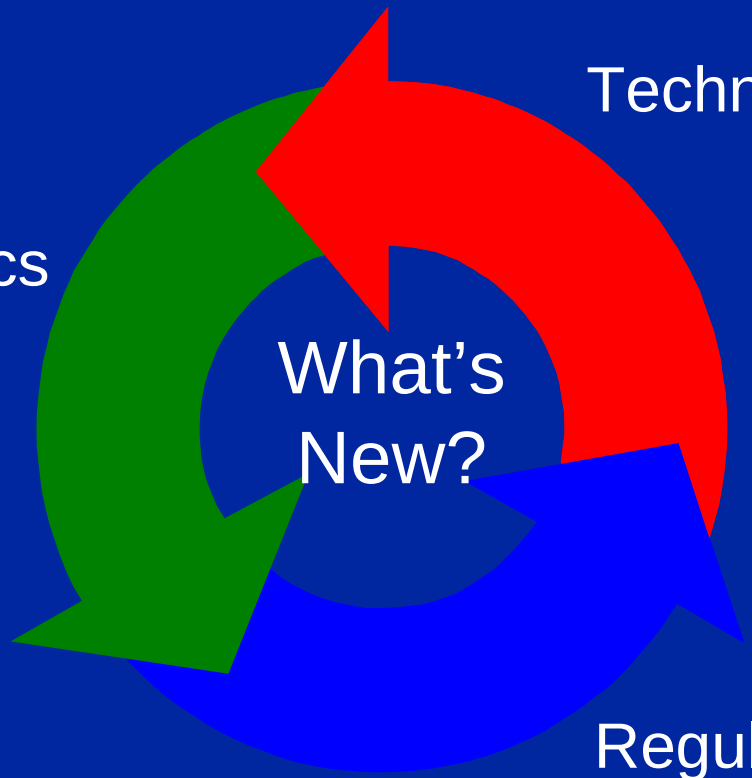


Satellites: What's New?

- Have been around for 40 years
  - October 1945: Arthur C. Clarke, *Wireless World*
  - October 4, 1957: Launching of the Sputnik



Satellite Deregulation

- Decline in the Dominance of Government-backed Consortia, like Intelsat and Inmarsat
  - 1987: Intelsat carried 50% of all international calls
  - 1997: Down to 10%, and declining
- Competition with private satellite operators and fiber optic cables
- Intelsat splitting into a separate “commercial” piece and government-sponsored telephony piece

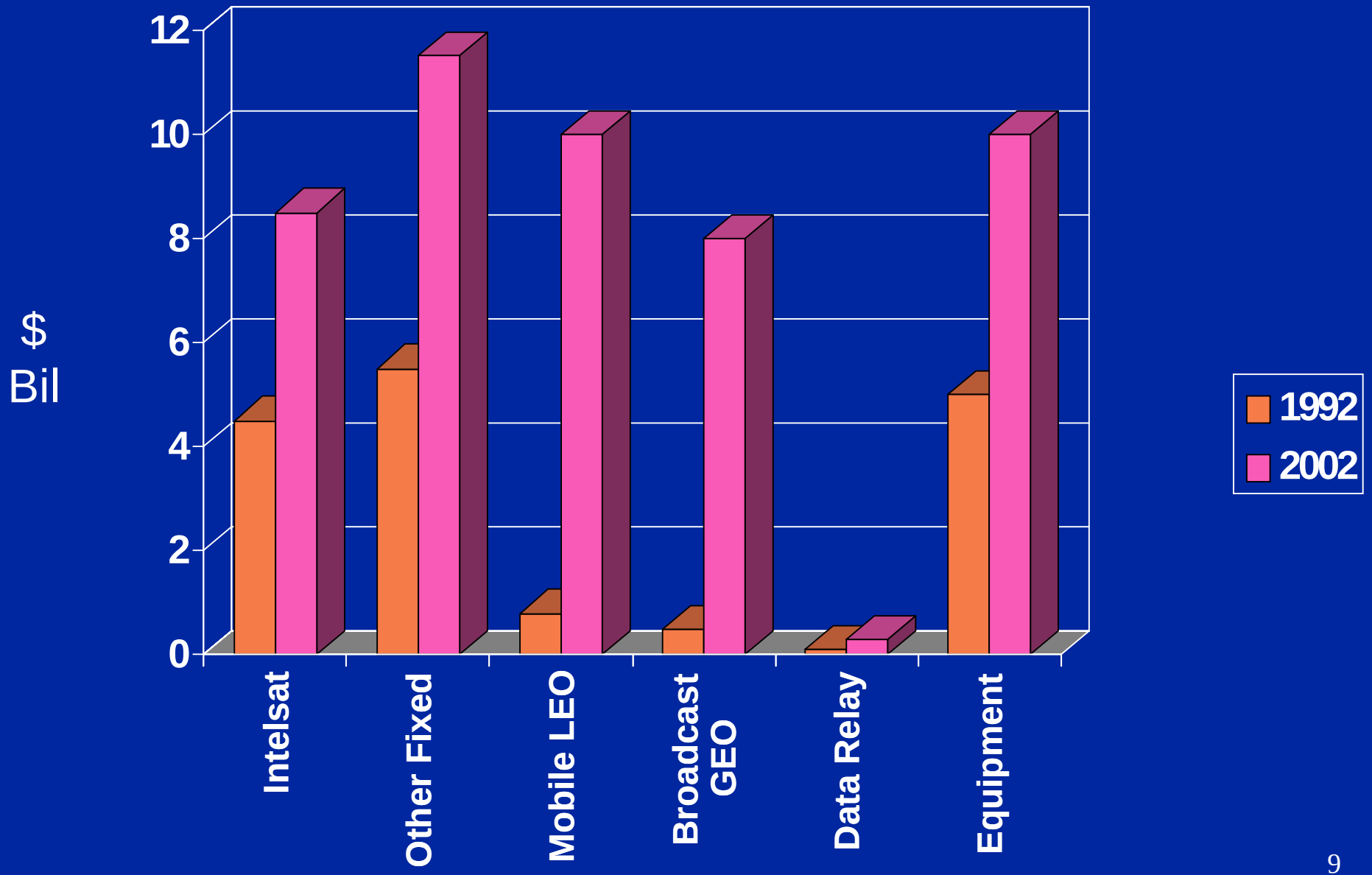
Satellite Economics

- Economic and Marketing Developments
  - Demand for communications infrastructure in the developing world
    - » China to add 100+ million telephone lines in the next few years
    - » Fastest growth in Asia and developing parts of the world
  - Direct-to-home broadcast services
    - » Telecommunications as the driver overtaken by consumer businesses, like direct broadcast TV
  - Internet access
    - » Low cost (??) strategy for providing broadband “bandwidth on demand” to very large number of users

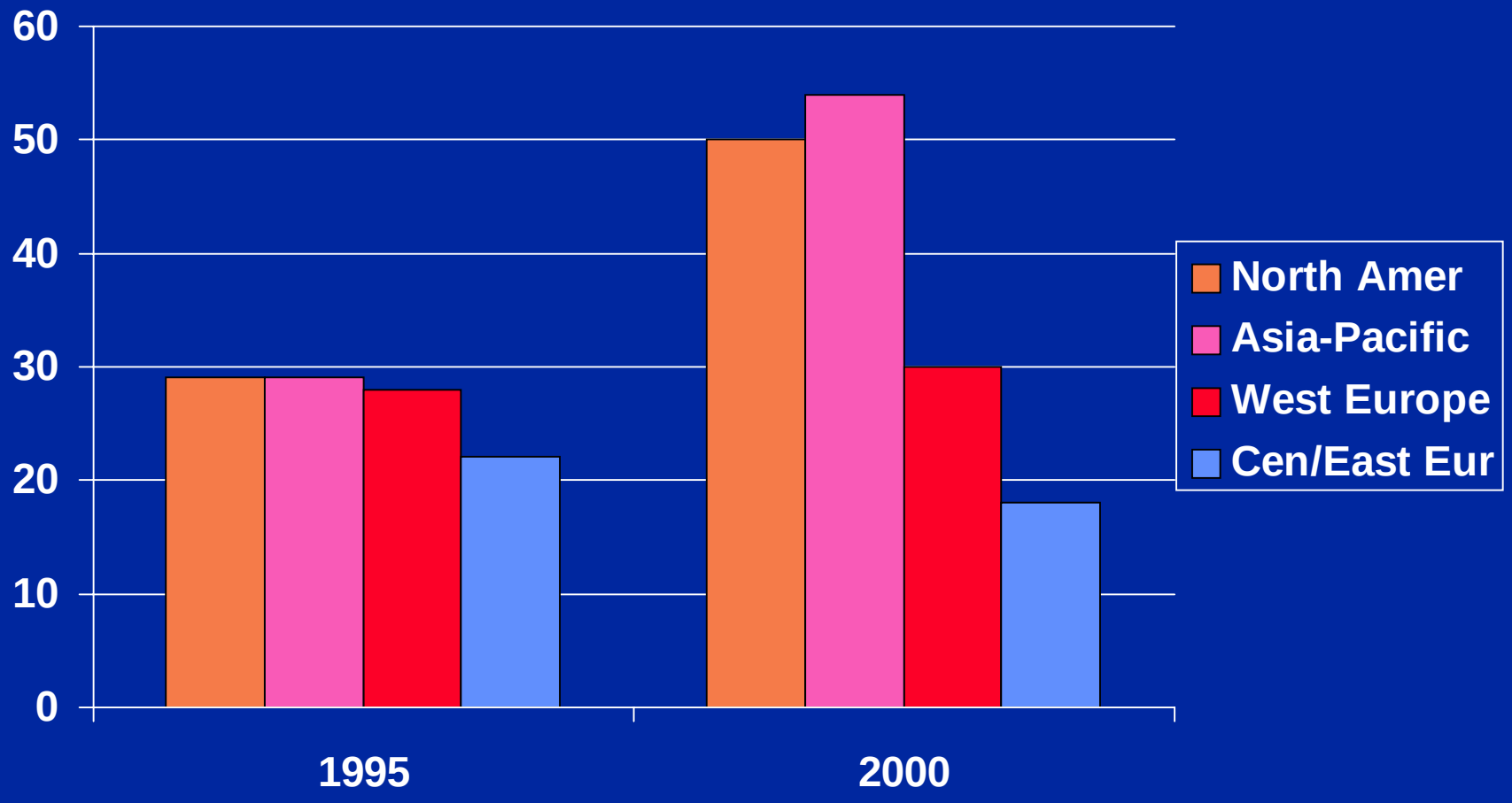
Size of the Satellite Market

- 1997
  - 1500 satellites of all types
  - 700 Ku-band satellites
  - 300 GEO satellites, representing over $18 Billion in services & equipment
  - As many satellites sold between 1995-1997 as sold throughout 1980s
  - 44 Iridium satellites in orbit by end of year
- 2003
  - Satellite population to grow to 2000, $60 billion
  - Shift to Ka-band
  - 1078 planned satellites for 14 different systems (mostly LEOs)

Predicted Global Markets in Satellite Communications Services



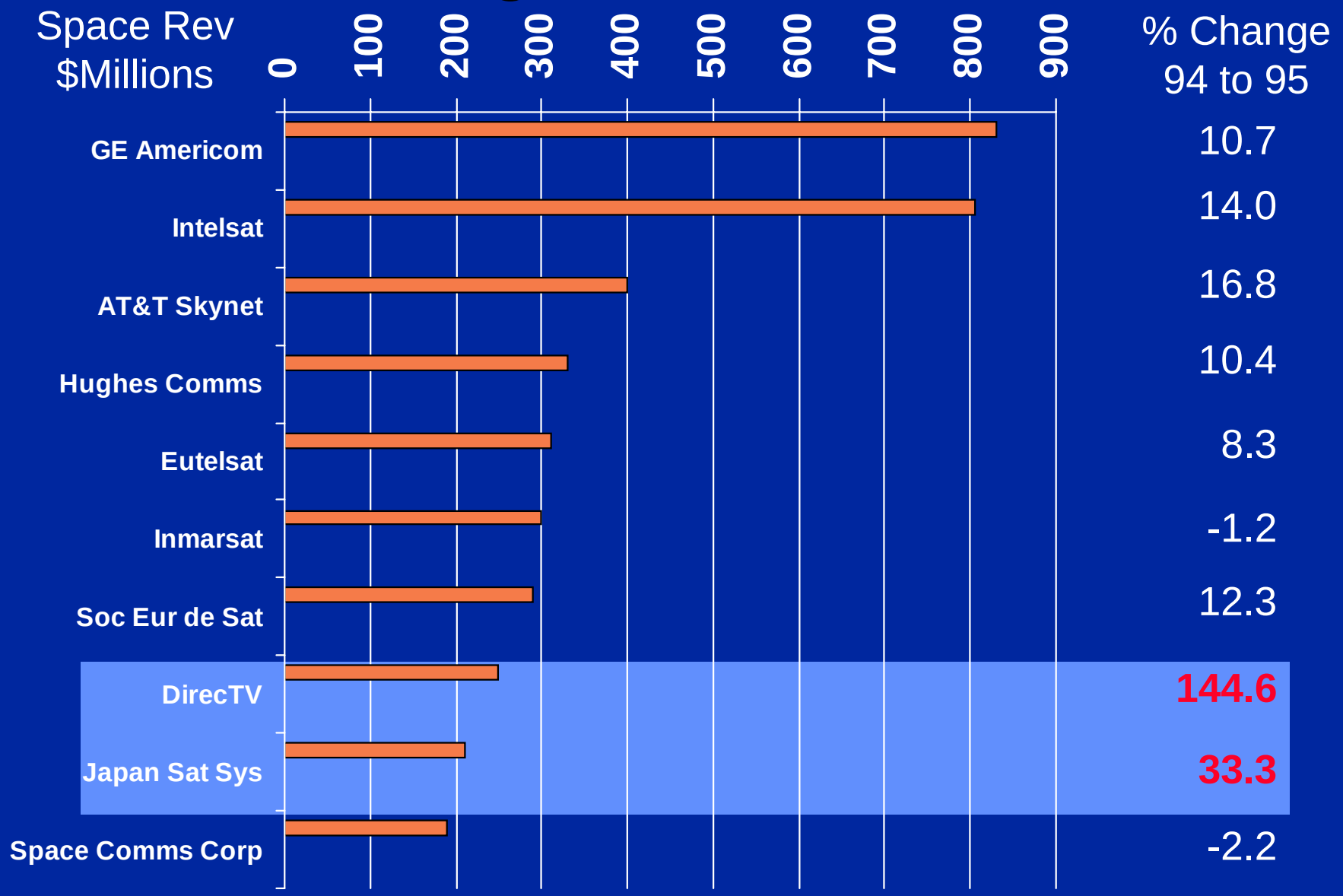
Worldwide Satellite Markets



% Growth by Region

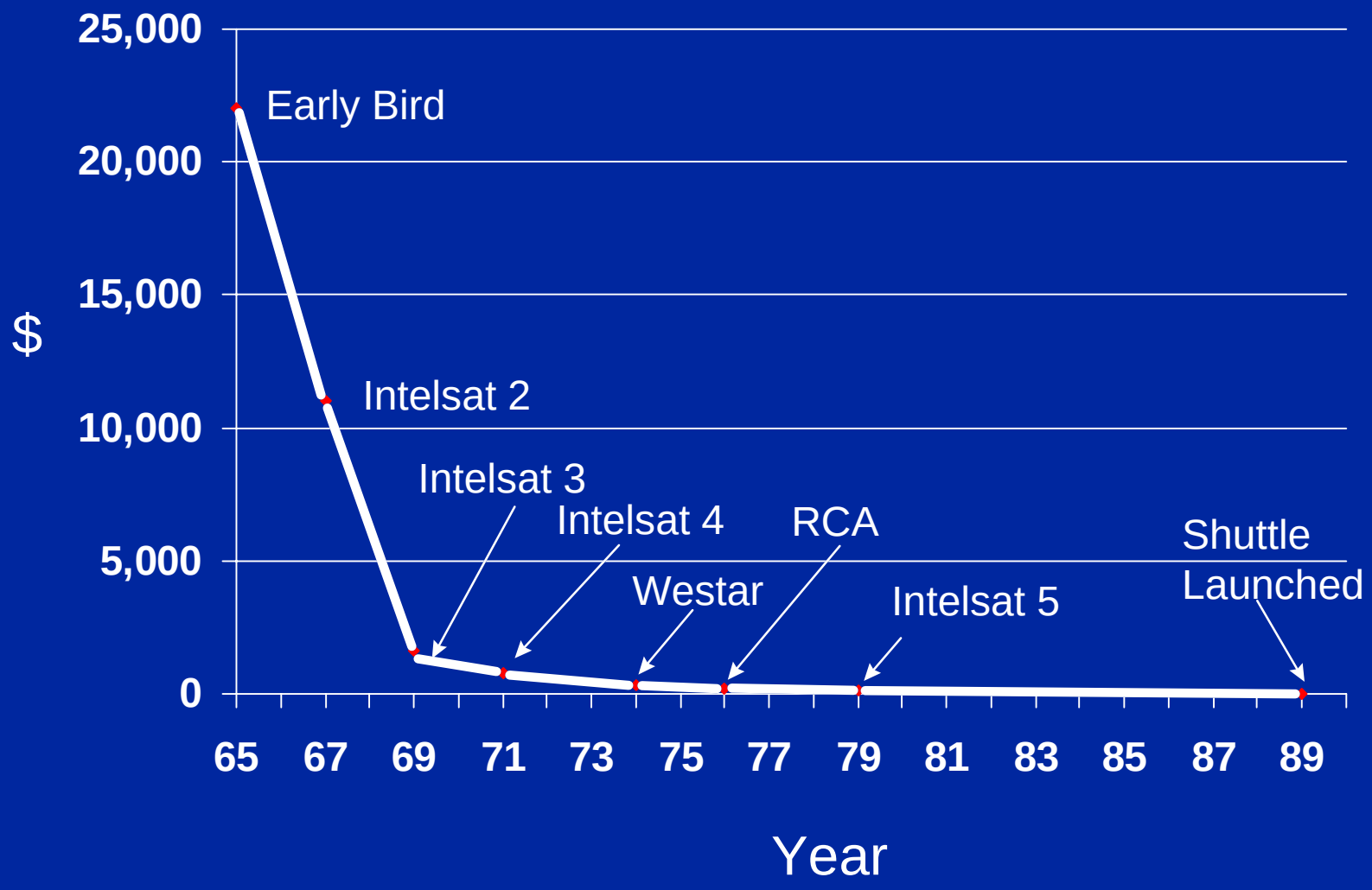
Source: Euroconsult, in the Economist Magazine, 5 Oct 96

Leading Satellite Services

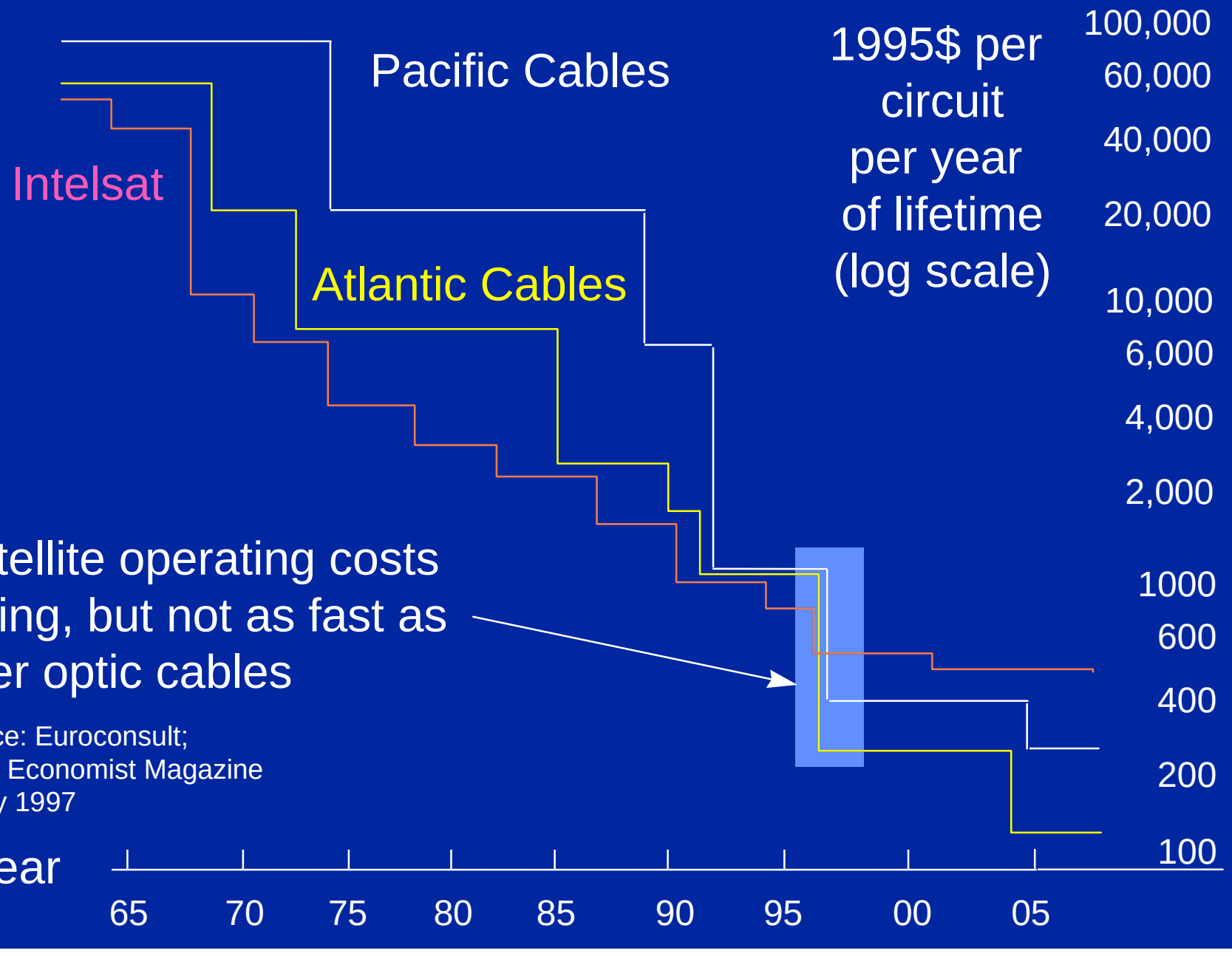


Source: Euroconsult, in the Economist Magazine, 5 Oct 96

Declining Costs/Voice Circuit



Transoceanic Cable & Satellite Costs



Satellite Service Penetration

(Int'l) Telephony	10% worldwide market and falling
Television	6% and rising (vs. 24% on cable) 1500 transponders in 1995 3350 transponders in 1997
Business Data	1% (approx. 200K VSATs) (potential $100 billion market)
Paging	0.3% (approx. 175K subscribers) Service since 1987
Mobile Voice	0.2% (130K subscribers) Available for over 18 years!

Is TV the Satellite Killer App?

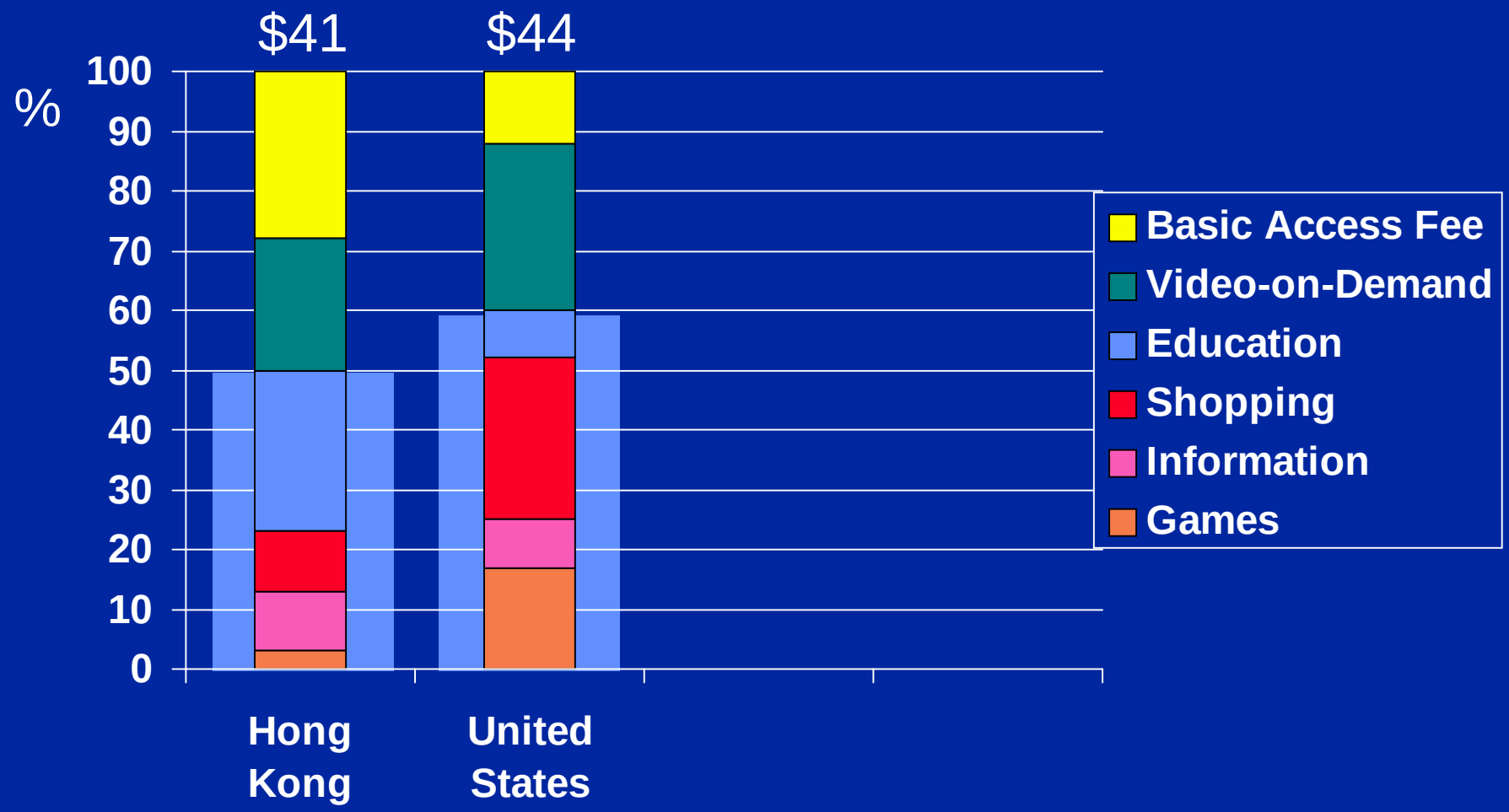
- Satellite capacity for voice and data
  - Asia: 50%
  - North America: 10%
- In developed regions, better suited for carrying TV signals, not telephony
- Much faster growth expected in direct-to-home satellite TV revenue than traditional telecommunications services
- Perferred transport?
  - MPEG-2 (Broadcast TV)
  - ATM (Telephony/“Integrated Services”)
  - Fast Packet Switching (“Internet Services”)

Forecast Satellite Revenue

(excludes mobile satellite services)

Source: Merrill Lynch, The Economist Magazine, 3 May 97

TV or Not TV?



Potential Monthly Revenue per subscriber household from multimedia applications, 1994

Source: ITU, The Economist, 4 Nov 95

Satellite Technology

- Technological Developments
  - On-board processing (OBP), beam switching and multibeam antennas, inter-satellite links
    - » Resource allocation on demand
    - » Space Division Multiple Access using spot beams
    - » Hubless operation
  - Ka-band
    - » Much higher aggregate data rates (2.5 GHz)
    - » Much smaller terminals (50 cm)
    - » Much lower operating costs
    - » C/Ku: 1.25-2.25 MHz/Kg; Ka: 2.25-4.75 MHz/Kg
  - Initial deployment of large-scale multisatellite LEO systems (Iridium)
    - » Reduced latencies
    - » Much larger global bandwidths

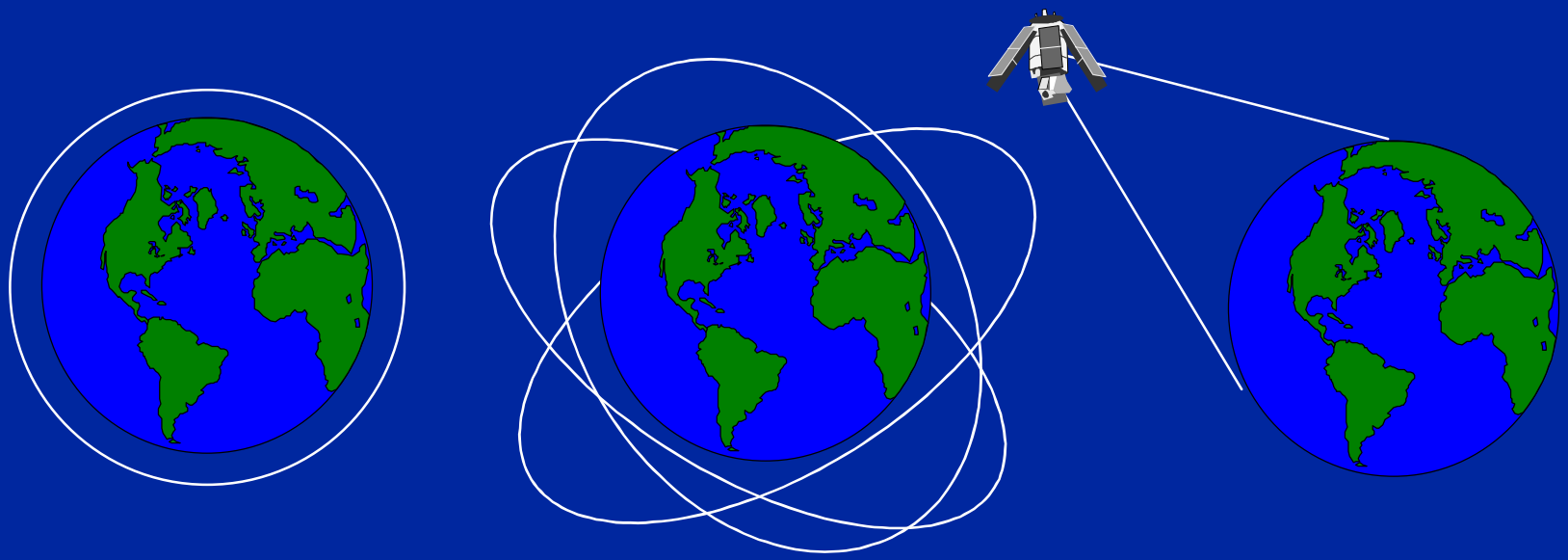
MSS vs. FSS

- Mobile Satellite Services
  - Communications for mobile users
    - » E.g., Iridium, GlobalStar, ICO, Odyssey, ...
    - » Big LEO telephony and low speed data
    - » Little LEO location tracking and low speed data
- Fixed Satellite Services
  - "Broadband" satellites offering much higher bandwidth "on demand" to fixed sites
    - » E.g., Teledesic, Spaceway, Celestri, ...
    - » Full multimedia services: broadcast and interactive video and audio, high data rate communications, even telephony (covering all of the bases!)
    - » Trunking and direct-to-the-premises

Alternative Orbits

NGSO

GSO



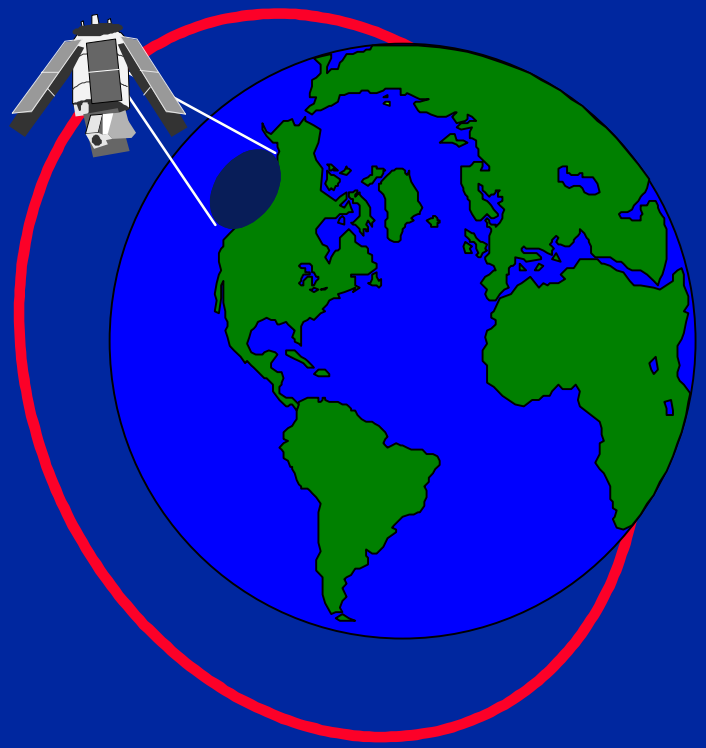
Low Earth Orbits
Height: 700-2000 km
Rotation Period: 90 min.
Time in LOS of
earth station: 15 min.

Medium Earth Orbits
Height: 8000-12000 km
Rotation Period: 5-12 hrs.
Time in LOS of
earth station: 2-4 hrs.

Geostationary Orbits
Height:35,780 km
Rotation Period: 24 hrs.
Time in LOS of
earth station: 24 hrs.

MSS vs. FSS

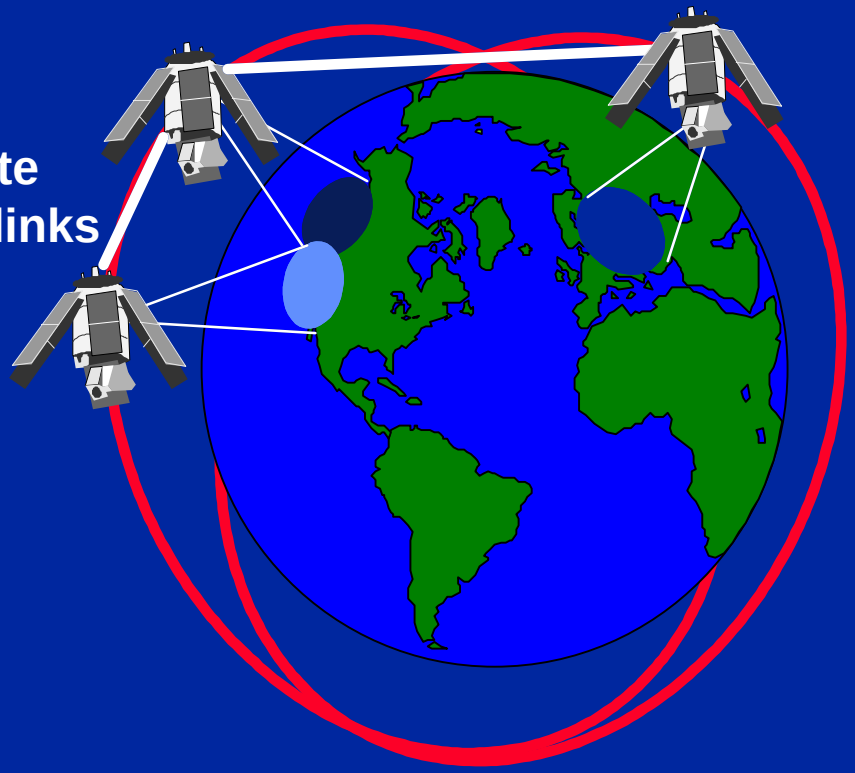
Hubless Architectures



Requires ES gateway
within sight of every satellite

Satellite
Crosslinks

"Hubless"



Intersatellite links
can reduce the need for
ES gateway coverage

Proposed Satellite Constellations

- Service/Orbit/# Satellites
  - ACeS/GEO/2
  - Africom/GEO/1
  - AMSC/GEO/2
  - APMT/GEO/2
  - ASC/GEO/2
  - Astrolink/GEO/9
  - Celestri/Broadband LEO/63
  - Celsat/GEO/3
  - Cyberstar/GEO/3
  - EAST/GEO/1
  - ECCO/Big LEO/46
  - Ellipso/LEO-MEO/17
  - E-Sat/Little LEO/6
  - Expressway/GEO/14
  - Faisat/Little LEO/26
  - GEMnet/Little LEO/38
  - GE*Star/GEO/5?
- Service/Orbit/# Satellites
  - GE Starsys/Little LEO/24
  - GemNet/Little LEO/38
  - Globalstar/Big LEO/48
  - ICO/MEO/10
  - Inmarsat3/GEO/5
  - Iridium/Big LEO/66
  - KaStar/GEO/2
  - Koskon/Big LEO/32
  - LEO One/Little LEO/48
  - Millenium/GEO/4
  - M-Star/Broadband LEO/72
  - Odyssey/Big LEO/12
  - Orbcomm/Little LEO/28
  - Skybridge/LEO/64
  - Spaceway/GEO/9
  - Teledesic/Broadband LEO/288
  - VITAsat/Little LEO/2

Alternative Broadband Constellations

- Hughes Spaceway
  - 8 GEO satellites
  - Hubless architecture
  - 48 communications beams per satellite @ 125 MHz each
  - 16 kbps to 6 mbps; single satellite thruput: 4.4 Gbps
  - $1000 consumer terminal

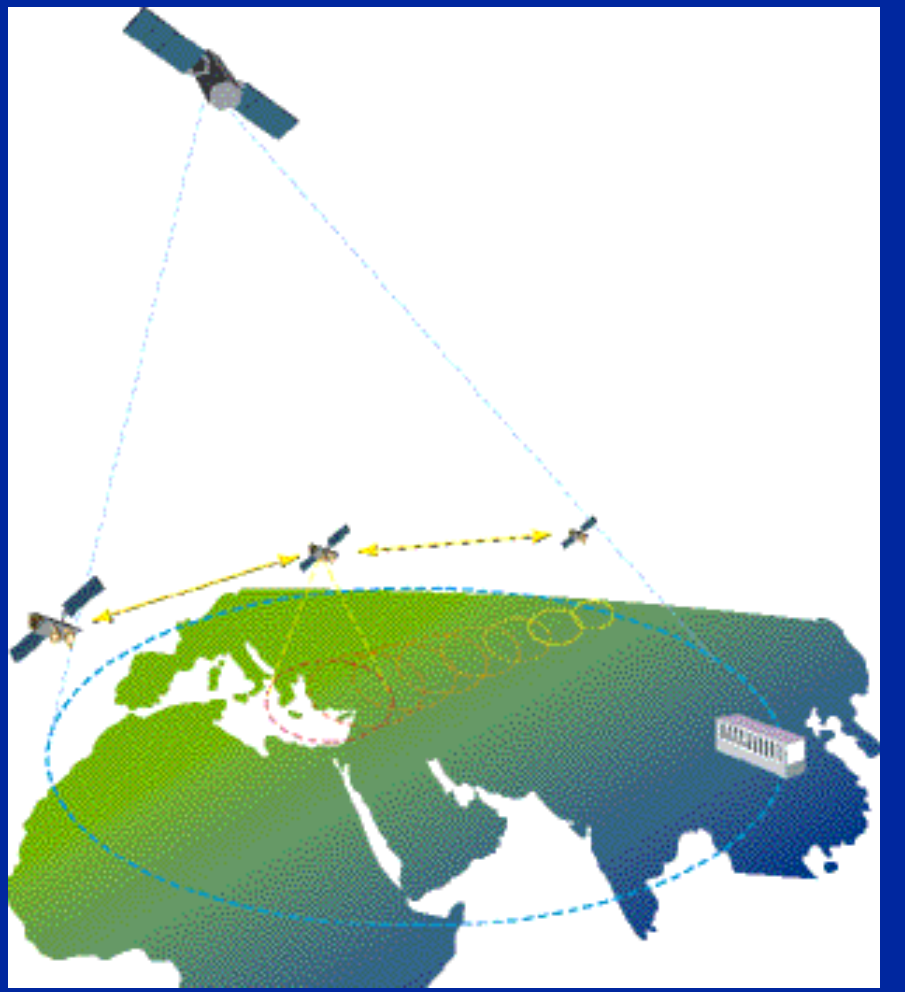
» 276,480 circuits @ 16 kbps	
» 34,560 circuits @ 128 kbps	
» 11,520 circuits @ 384 kbps	Standard USAT: 66 cm
» 2,880 circuits @ 1.544 mbps	Enhanced USAT: 1.2m
» 1,440 circuits @ 3.088 mbps	
» 720 circuits @ 6.176 mbps	Broadcast: 3.5m

Alternative Broadband Constellations

- Teledesic
  - 288 LEO sats in slightly inclined orbits
  - ISLs to 8 adjacent sats @ 155 mbps to 1.2 Gbps
  - 16 kbps to 2.048 Mbps to 1.2 Gbps
    - » Standard terminal: 16 kbps to 2 Mbps, 16 cm to 1.8 m
    - » High speed terminal: 16 kbps to 64 Mbps
    - » Gigabit terminal: up to 1.2 Gbps
  - Each satellite supports 125,000 16 kbps channels
  - Cellular Architecture
    - » 160 km x 160 km “supercells” with 53 km x 53 km cells
    - » Satellite footprint spans 64 supercells/576 cells
    - » 18 x 1.5 mbps links per cell, 20,000 such links worldwide

Alternative Broadband Constellations

- Motorola Celestri
  - 63 LEO Satellites
    - » 7 inclined planes
      1400 km altitude
  - 1.9 hour orbit period,
  - 65 degrees N and S latitude
  - Total capacity: 80 Gbps
  - Per Satellite:
    - » 432 up links, 260 down links
    - » 6 ISLs at 4.5 Gbps
    - » Switching rate: 17.5 Gbps
    - » Aggregate data rate: 8.7 Gbps
  - Motorola Hybrid Systems
    - » Celestri: interactive multimedia services
    - » M-Star: backhaul and high-capacity trunking for multinationals
    - » Millennium: interactive video, broadcast data

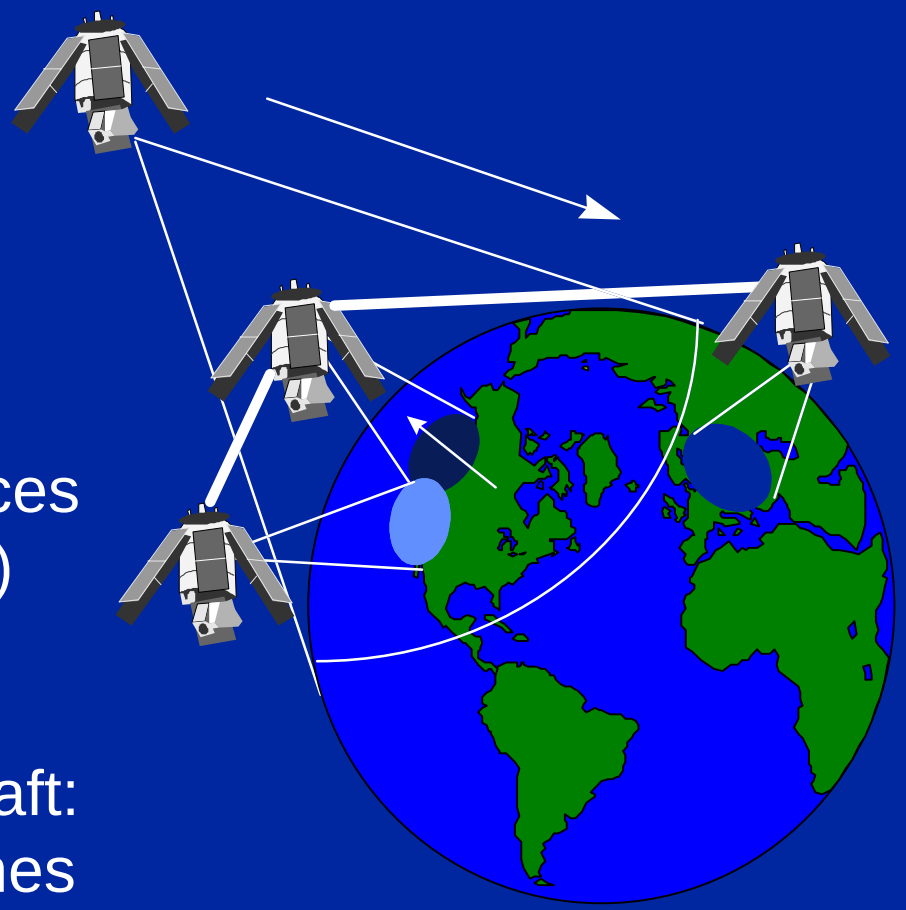


Hybrid Architectures

GEO or MEO-based
Broadcast/Multicast
(e.g., Millennium)

LEO-based return,
low latency/interactive services
(e.g., M-Star plus Celestri)

Recent ideas on HALE aircraft:
Angel Technologies--Airplanes
Sky Station--Blimps



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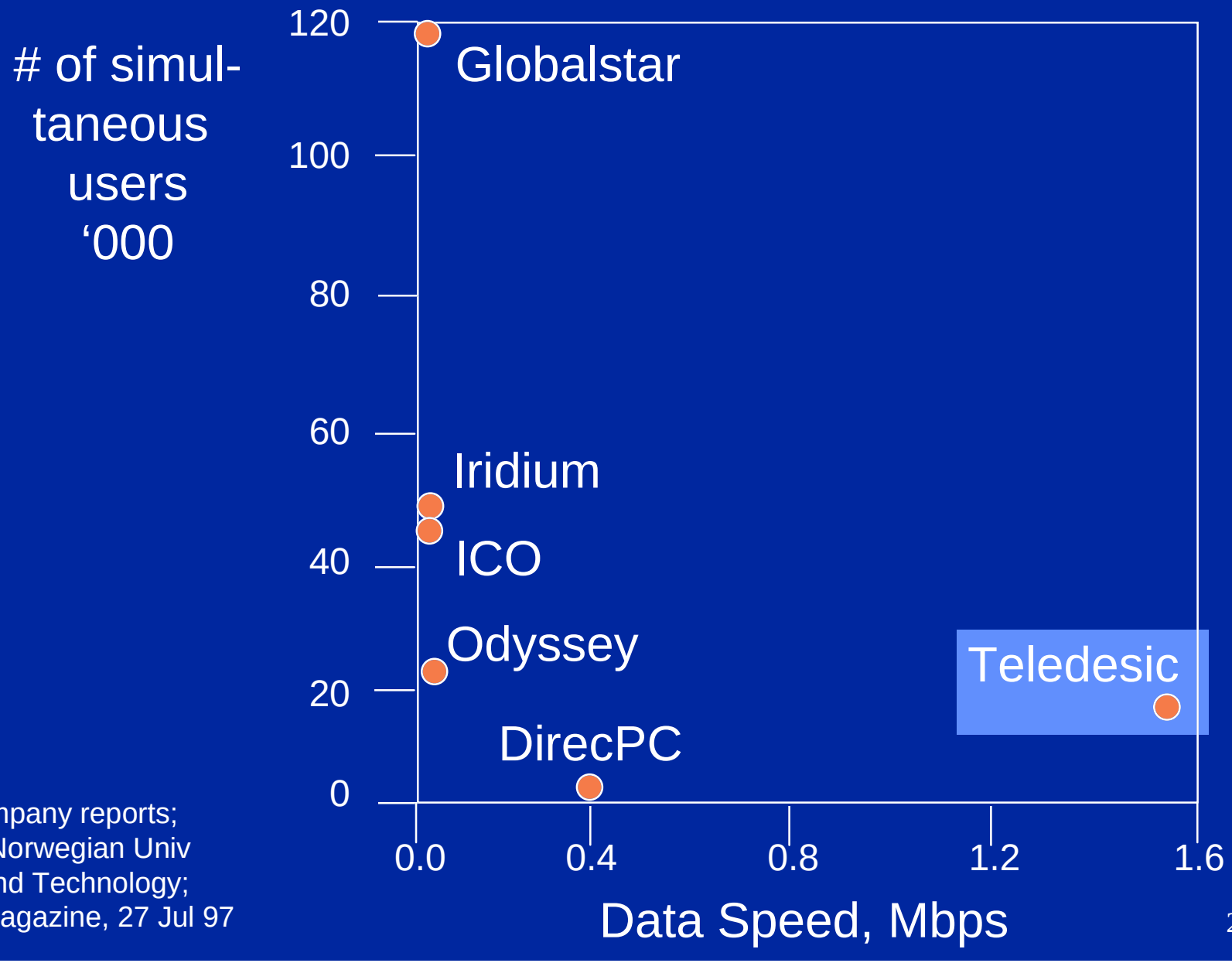
Satellites and the Internet

"Linking every home in the World to the Internet through fiber optic cable would cost $300 billion. To do the same think with global satellite coverage would cost about $9 billion."

FCC Commissioner Susan Ness

Do you agree?

Satellite Capacity/Performance



Sources: company reports; Tor Wisloff, Norwegian Univ of Science and Technology; Economist Magazine, 27 Jul 97

The Competition

- Wireless cable at 10-30 mbps
  - Requires LOS to transmitter
- Cable modems at 10 mbps
  - Cable TV passes many homes in North America, but not so true elsewhere in the world
- ADSL at 6 mbps
  - Requires modest distance from Teleco CO (12,000 ft/3700 m) for high data rates
  - High percentage of European homes near a CO (80-95%), not true in US (50%)

Can an advanced technology be funded primarily by deployments in the developing world?

Technical Challenges

- Media Access
  - Contention access from 100,000s of users?
- Routing in Multiple Satellite Networks
  - Moving meshes of satellites, bypassing congested nodes over major metro regions
  - Multicast support
- Asymmetries in Latency, Packet Losses
  - Careful management of the ACK stream
- Large Bandwidth-Delay Products
  - Sustaining high throughput in the face of high latencies and packet losses
- Terrestrial-Satellite Integration
  - QoS negotiation across hybrid technologies

Transport Issues

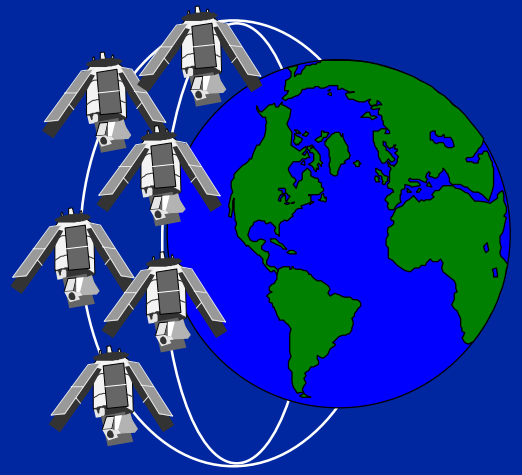
- Latency
  - Three way handshakes/session-oriented concepts
- Performance
  - Scaled windows for TCP (RFC 1323) and other schemes to circumvent TCP slow-start behavior
    - » Shared contention window state
  - Terrestrial/satellite integration via ACK spoofing
  - Alternatives to combat large delay-bandwidth products
    - » Optimize for the common case: NACK-based retransmission rather than ACK-based clocking
- Asymmetric Transport
  - DBS forward link, terrestrial return links
    - » ACK filtering, ACK congestion control, ACK priority, ACK reconstruction, other ideas

Routing Issues

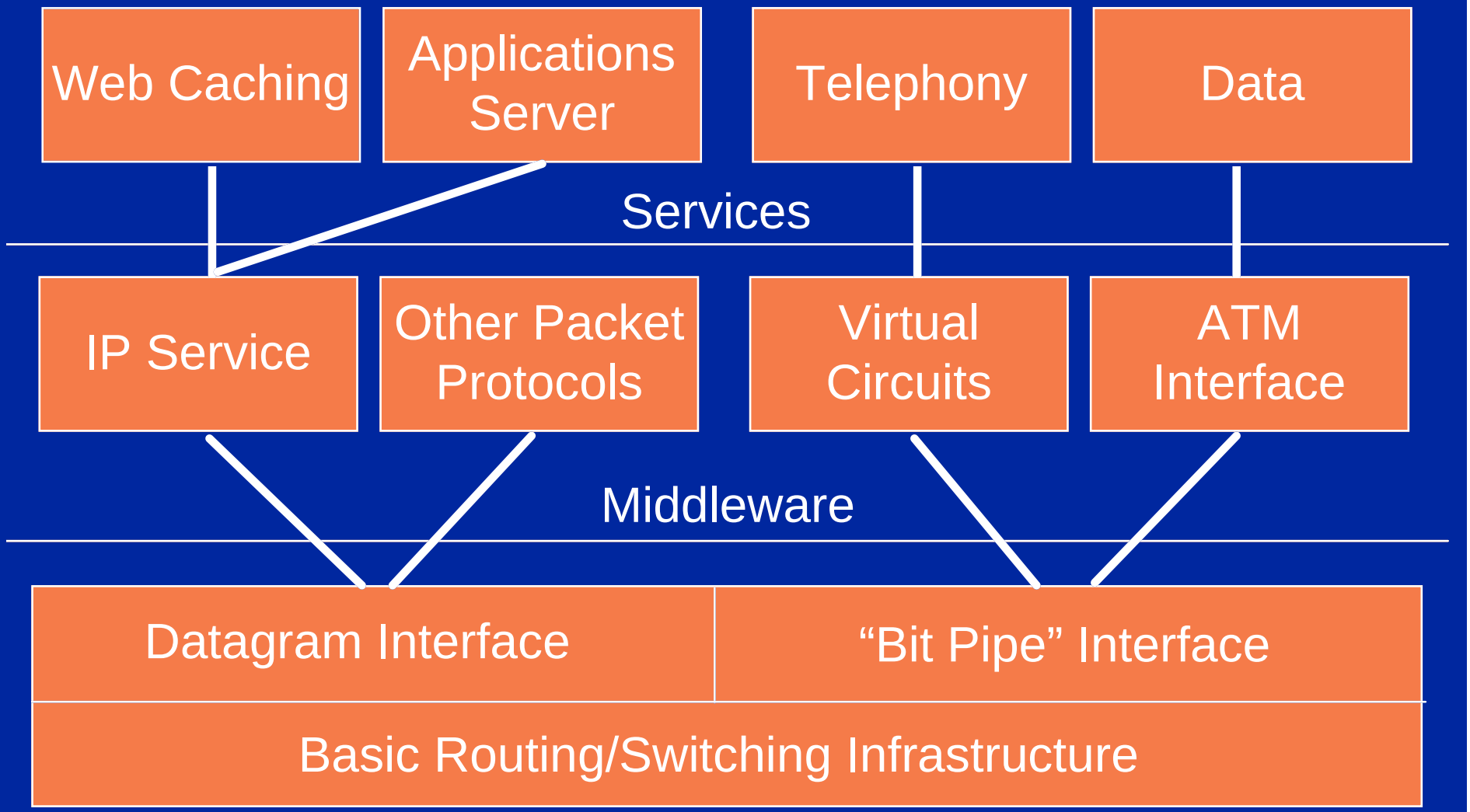
- How should satellite hardware support multicast?
- Efficiency and convergence of routing algorithms for sparse multicast groups
- Exploiting routing hierarchy to support (hundreds of) thousands of receivers
- Reliable multicast protocols/reservation protocols
- Split-session and asymmetric routing
  - Delay-sensitive data over terrestrial or LEO network
  - Delay-insensitive data over GEO network
  - DBS or hybrid systems with unidirectional links
- Broadband terminal mobility/subnetwork mobility
  - Satellite connectivity to planes, trains, and ships

Routing in LEO Constellations

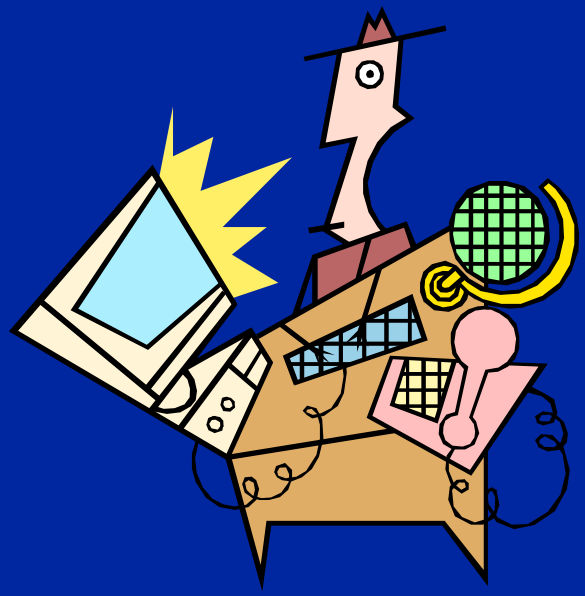
- Dynamic routing through the satellite mesh
  - Global routing and addressing
  - Geographical addressing
- Rapidly changing angles among the satellites dramatically effects link quality
- Calculate in advance the trajectory through the mesh given information about buffer residency time and current state of the satellite network



Integrated Services



Applications, Applications, Applications

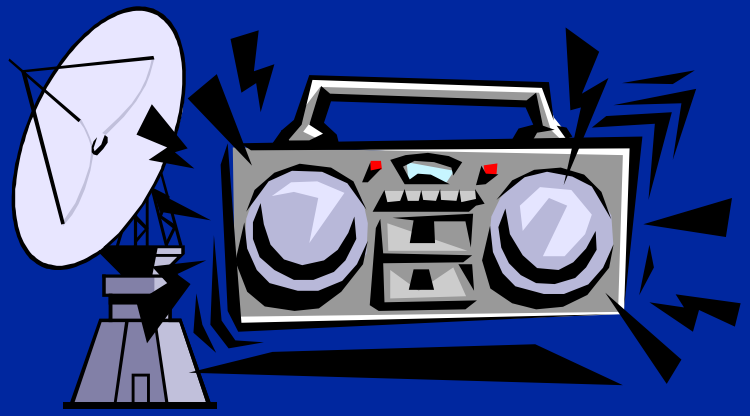


- Desktop video conferencing
- Computer networking
- Tele-medical imaging
- CAD/CAM transmission
- Distance learning
- Multimedia database/digital library access
- High speed Internet access
  - Latest Holy Grail: direct-to-end-user
- Infrastructure on demand
  - Bypass the “swamp”: ISP-to-POP
  - Reduce Internet complexity diameter

Is the Killer App Broadcast Data?

- Satellites extremely efficient when information is broadcast to many simultaneous users, e.g., satellite television
  - Point/Multipoint-to-Multipoint Services
  - Videoconferencing
  - Push Information Dissemination

- For satellites to become broadly successful, new applications will be necessary



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Summary and Conclusions

- Applications, applications, applications
  - Voice is NOT the killer app, but is it TV or Internet? Or some hybrid of broadcast and interactive access
  - Important work to be done: how these systems can be used in mixed broadcast and transactional access
    - » Development/testing of protocols for large-scale media access, routing (unicast, multicast) in multisatellite systems, transport
- Too much capacity?
  - If all of the proposed constellations get built by 2010
    - » 1.3 billion x 64 kbps call minutes
    - » Enough for 4000 hours per person per year!
    - » Many of the proposed systems will not be built (or someone is going to lose a lot of money!)