High-Capacity Ground Communications to Support Future Space Missions

A Forecast of Ground Communications Challenges in the 2010-2020 Period

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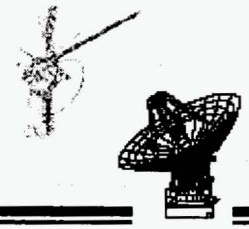
Purpose



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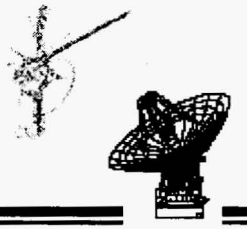
The purpose of this presentation is to identify major challenges involved in space ground communications networks to support space flight missions over the next 20 years.

The presentation focus is on the Deep Space Network and its customers, but the forecast is applicable to all space ground communications networks.

Introduction



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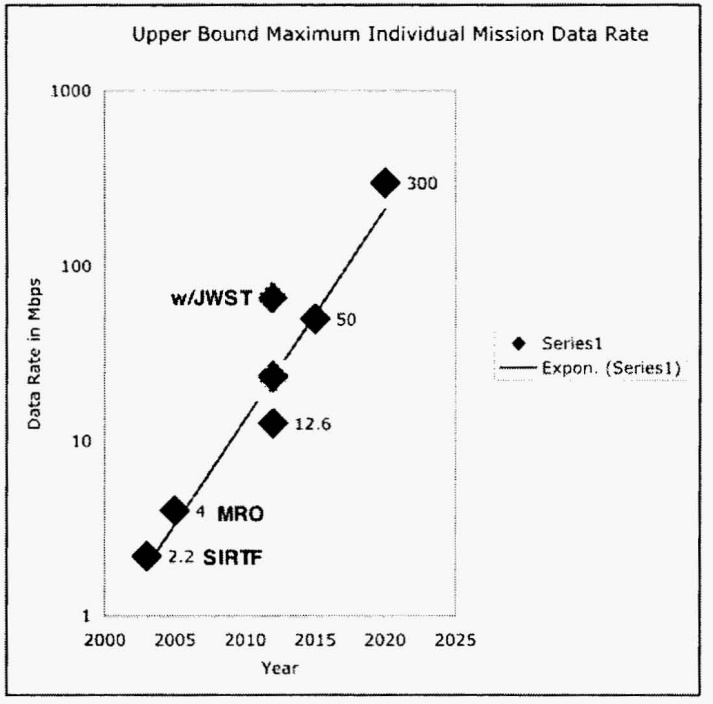
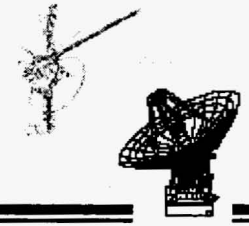
- Number of DSN-supported missions will remain relatively constant (~28) unless there is a new business base.
- **Growth in individual mission rates are exponential, a factor of approximately 10 every 10 years.**
- Mission concepts more than 10 years out exhibit a heavy bias towards today's technologies. For 2020 analysis, Douglas Abraham looked at instrument data rates required to perform remote sensing at other planets with the same fidelity as at Earth.
- Aggregate mission loading at each complex is uncertain.



- Maximum anticipated deep space mission data rates:
  - 2012: 21Mbps
  - 2015: 50 Mbps
  - 2020: 300 Mbps

Source: Douglas Abraham, SpaceOps 2002 T3-64

DSN 2003



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Highest Capture Rate: 2.2 Mbps (IMAGE, SIRTF)

Aggregate Transfer Rate: 2.7 Mbps (CY03 QTR4 @ MDSCC)

Includes Real-Time: 0.7 Mbps

Major Network Features:

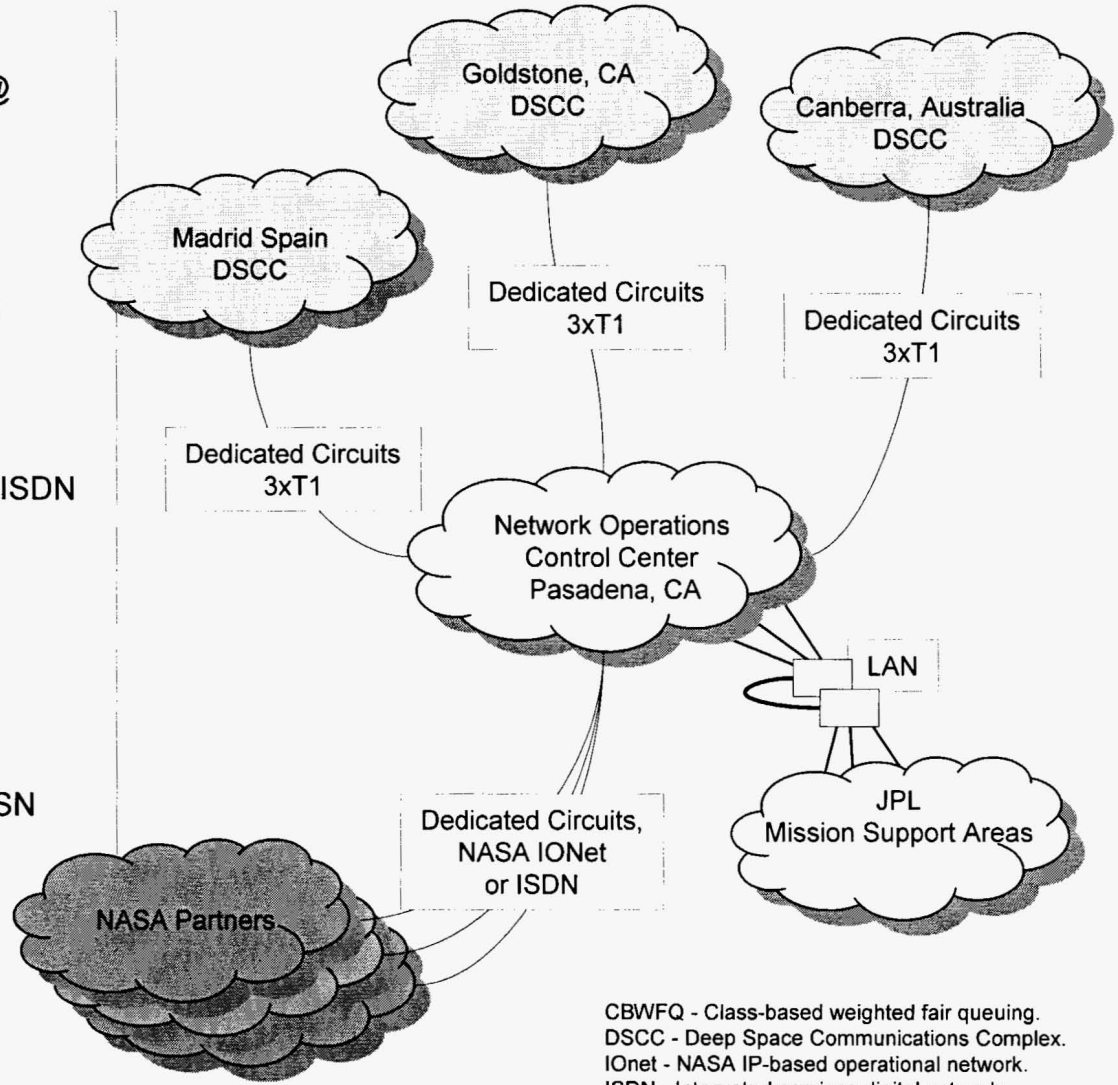
- **Total dependence on dedicated circuits to DSN complexes.**
- MLPPP - unified IP pipe to each complex.
- CBWFQ - priority to specific classes of traffic.
- Dedicated circuits, shared NASA IOnet, and a few ISDN interfaces to off-site partners.

NASA DSN Costs.

3 T1s 1.5 Mbps $3.1 million

Not Shown

Dedicated multiplexer channels for video, voice, DSN Admin.



CBWFQ - Class-based weighted fair queuing.
DSCC - Deep Space Communications Complex.
IOnet - NASA IP-based operational network.
ISDN - Integrated services digital network.
LAN - Local area network.
MLPPP - Multi-Link Point-to-Point Protocol. 7/15/03
T1 - 1.5 Mbps dedicated circuit.

Basis for Network Planning

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Infrastructure support (primarily voice over IP) and remote monitor.

+

Real-time streams that may be tracked simultaneously. May range from 10 bps to 100 kbps or more. Standard allowance for the streams is 300 kbps.

+

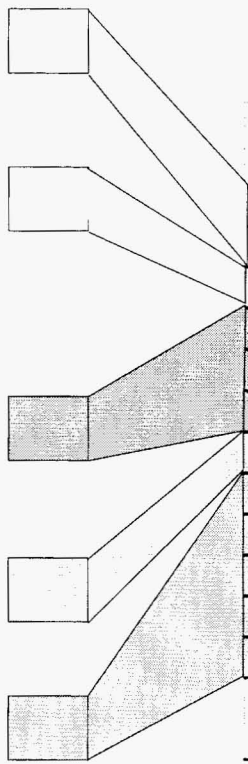
Exceptional real-time, low-latency streams with higher rates not included in the baseline.

+

High-volume, non-real-time FTP data flows such as Delta DOR.

+

Playback streams, averaged over the committed delivery time. Assume all flow simultaneously.



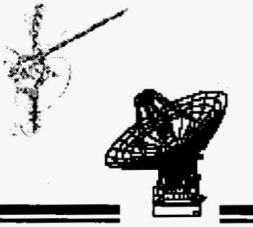
Classes of Service and Rates

Data Source	Volume (Gbytes)	Deliv Time (hrs)	WAN Rate (kbps)
Infrastructure Support (VOIP)			100
Remote Monitor DSCC 60			357
Real-Time Est w/o SOHO, etc.			300
Exceptional R-T Streams			
SOHO			368
Cassini			35
Delta DOR	2.5	8	695
Playbacks			
CHANDRA	0.4	6	148
IMAGE	0.514	6	190
MAP	0.223	4	124
SIRTF	0.99	6	367
Total WAN Rate			**2684**

- MDSCC 2003

Delta DOR - Delta differential one-way range measurements taken periodically during cruise and approach for spacecraft navigation.
DSCC- Deep Space Communications Complex
MDSCC - Madrid DSCC
VOIP - Voice over IP
WAN - Wide area network

Trends: Dedicated Lines



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Industry Focus

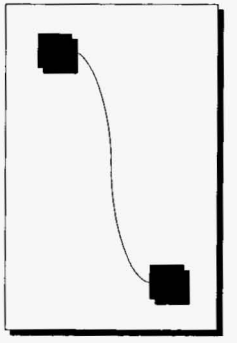
- **Physical Layer:** Fiber optic cable, dense wavelength division multiplexing (DWDM), satellite communication, wireless communication.
- **Link Layer:**
  - WAN: SONET OC-384 (20 Gbps), OC-768 (40 Gbps), OC-3072 (160 Gbps), SONET, Synchronous Optical Network OC-n, Optical Carrier (at multiple level) n.
  - LAN and MAN: 10G Ethernet, 40G Ethernet, 160G Ethernet.

Basis for Growth

- **Advances** in fiber optics and microelectronics.
- **Demand** for IP-based services and an increase of applications and communications.

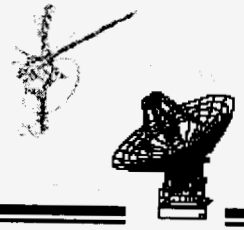
Forecast

- Highest bandwidth listed above (160 Gbps) will be realized by approx. 2010.



Source: Joseph Liu

Trends: Internet



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Current Status

- Some estimates say 80% of the Internet backbone is not being used.
- The first reason is the **"last mile problem"** where the bandwidth from the home to the fast fiber backbone is not fast enough. The second reason is the **lack of services**.

Bandwidth Drivers

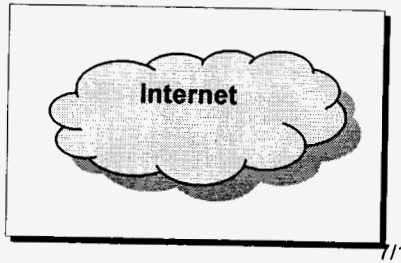
- Bandwidth growth will be driven by the service requirements. With the new multimedia technology, we can expect to see HDTV-level video and high-fidelity audio as a part of the typical web site. The multimedia web site today will be considered "primitive" in a couple of years. If a typical home is going to watch HDTV-level quality video from the Internet, this home may need somewhere around 2 to 5 Mbps.

Cost Driver

- If we use today's price that a consumer is willing to pay, the 2 to 5 Mbps bandwidth to the home should cost $30-$100 per month.

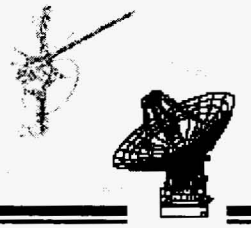
Forecast

- Much faster "last mile" bandwidth, at lower cost.
- Replaces (or includes) the video cable system today.
- Multicast enabled, QOS guaranteed, and much more reliable than today.



Source: Edward Chow

Trends: IP Services



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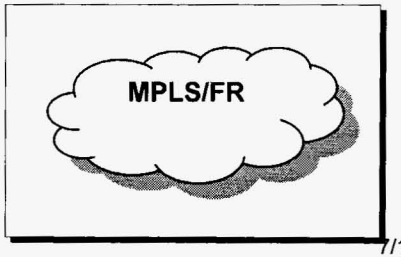
- **Frame Relay (FR) Service**
  - Shared dedicated circuits.
  - Frame Relay typically operates at 56 kbps to 1.544 Mbps.
  - Permanent virtual circuit (PVC) is dedicated connection through the shared Frame-Relay network replacing a dedicated end to-end line.
  - Bandwidth is shared among multiple users.

- **Multi-Protocol Label Switching (MPLS)**
  - Shared carrier Internet infrastructure.
  - Secure services provide VPN encryption.
  - Estimated costs are 30% of the cost of a dedicated circuit.
  - Various classes of service (COS) are available within the same path.

Typical Classes of Service			Distribution
Real Time	Minimum latency	VOIP, low-latency data	30%
Interactive	Minor Latency	Complete data	40%
Best Efforts	Subject to congestion	File transfers, email	30%



Current Cost Estimates

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Dedicated Circuit Cost Estimates			
	1.5/2.0 Mbps T1/E1	34/45 Mbps T3/E3	100/155 Mbps Fast Enet/OC-3
CDSCC	650k	1,950k	5,800k
GDSCC	20k	120k	360k
MDSCC	350k	1,050k	3,150k
Total	**$1,020k**	**$3,120k**	**$9,310k**

Internet Access Cost Estimates			
	1.5/2.0 Mbps T1/E1	34/45 Mbps T3/E3	100/155 Mbps Fast Enet/OC-3
CDSCC	70k	350k 400 GB	390k 400GB
GDSCC	20k	160k	320k
MDSCC	70k	320k	560k
Total	**$160k**	**$830k**	**$1,270k**

Internet access cost is approx. 10%-20% of the cost of a dedicated circuit.

Rules of thumb:

1. Costs OC3 = 3 x T3.
2. Assume Internet OC-12=3xOC-3 costs.
3. Costs based on informal budgetary cost estimates from carriers.

Architecture – Year 2010

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Highest Capture Rate: 12.6 Mbps
Aggregate Transfer Rate to JPL: 22.8 Mbps @ MDSCC
Includes Real Time: 2.3 Mbps

Major Network Feature:

Significant Operational Traffic Moves over to Public Internet.

1. Non-time sensitive traffic moves to Public Internet with security safeguards.
2. Voice and video transition to VOIP/VIP over Dedicated circuits.
3. Delivery to off-site partners via dedicated circuits, ISDN, proven Carrier Services, or Public Internet.

NASA Cost based on FY03 costs.

2xT3 cost: $6.2 million

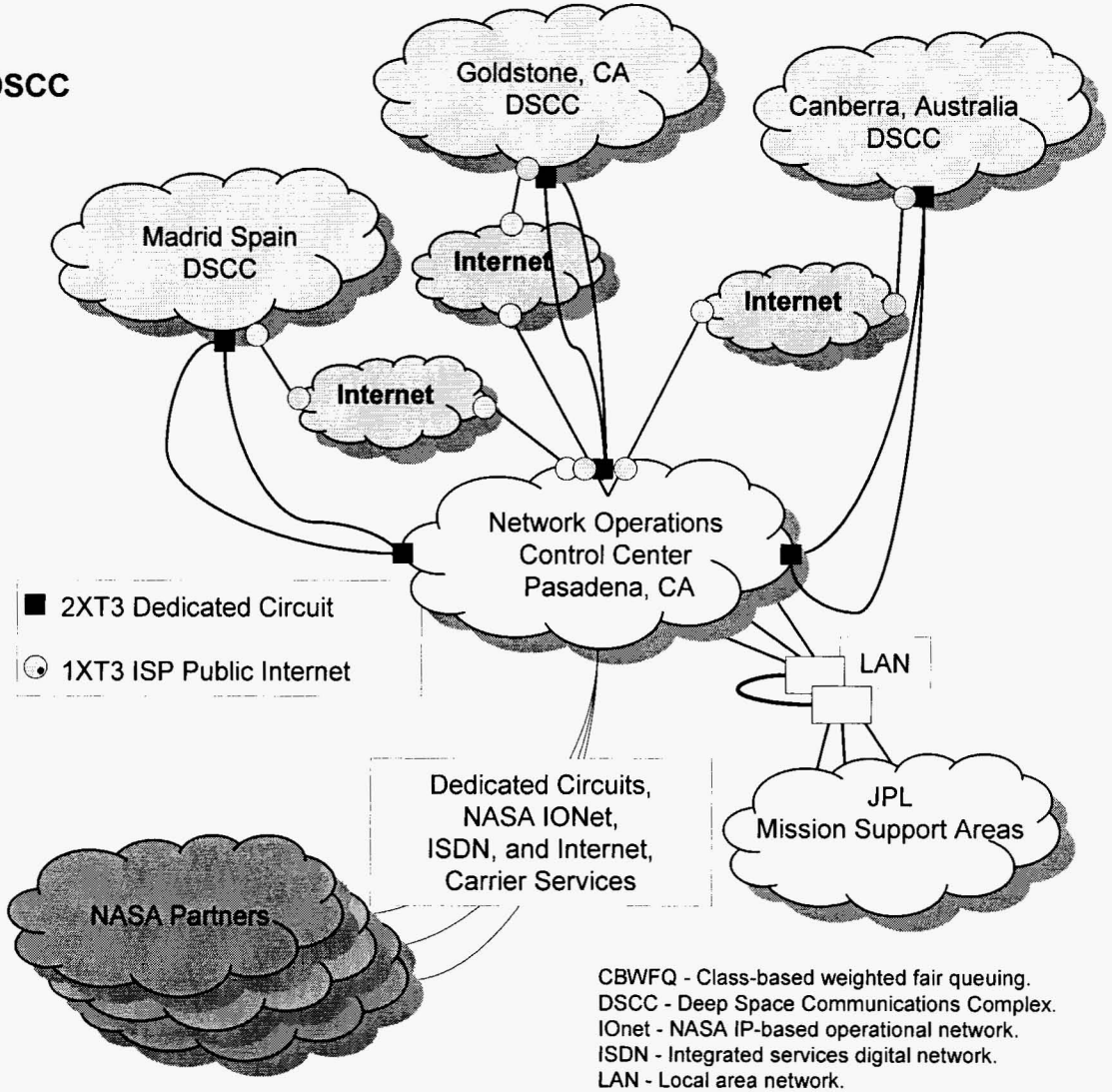
T3 ISP Internet Service: $0.8 million

Total 3@2xT3+T3 ISP= $7.0 million

If dedicated circuits, ~$9.4 million/yr

Uncertainties

1. Support for JW Space Telescope.
2. Implementation of the DSN Large Array and Optical Network.



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IOnet - NASA IP-based operational network.
ISDN - Integrated services digital network.
LAN - Local area network.
MLPPP - Multi-Link Point-to-Point Protocol.
T1 - 1.5 Mbps dedicated circuit.
T3 - 45 Mbps dedicated circuit.

Architecture – Year 2020

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Highest Capture Rate: 300 Mbps
Aggregate Transfer Rate to JPL: Est. 600 Mbps
Includes Real Time: 60 Mbps

Major Network Feature:

1. **All Real-Time Operational Traffic moves to Carrier services with dual entry points.**
2. **All Non-Real-Time Operational Traffic Moves to Internet with security safeguards.**
3. Introduction of strict networking controls to complete QoS implementation:

- Traffic policing / Admission control.
- Traffic shaping / metering (Deliver traffic only as soon as required).

NASA Cost based on FY03 costs.

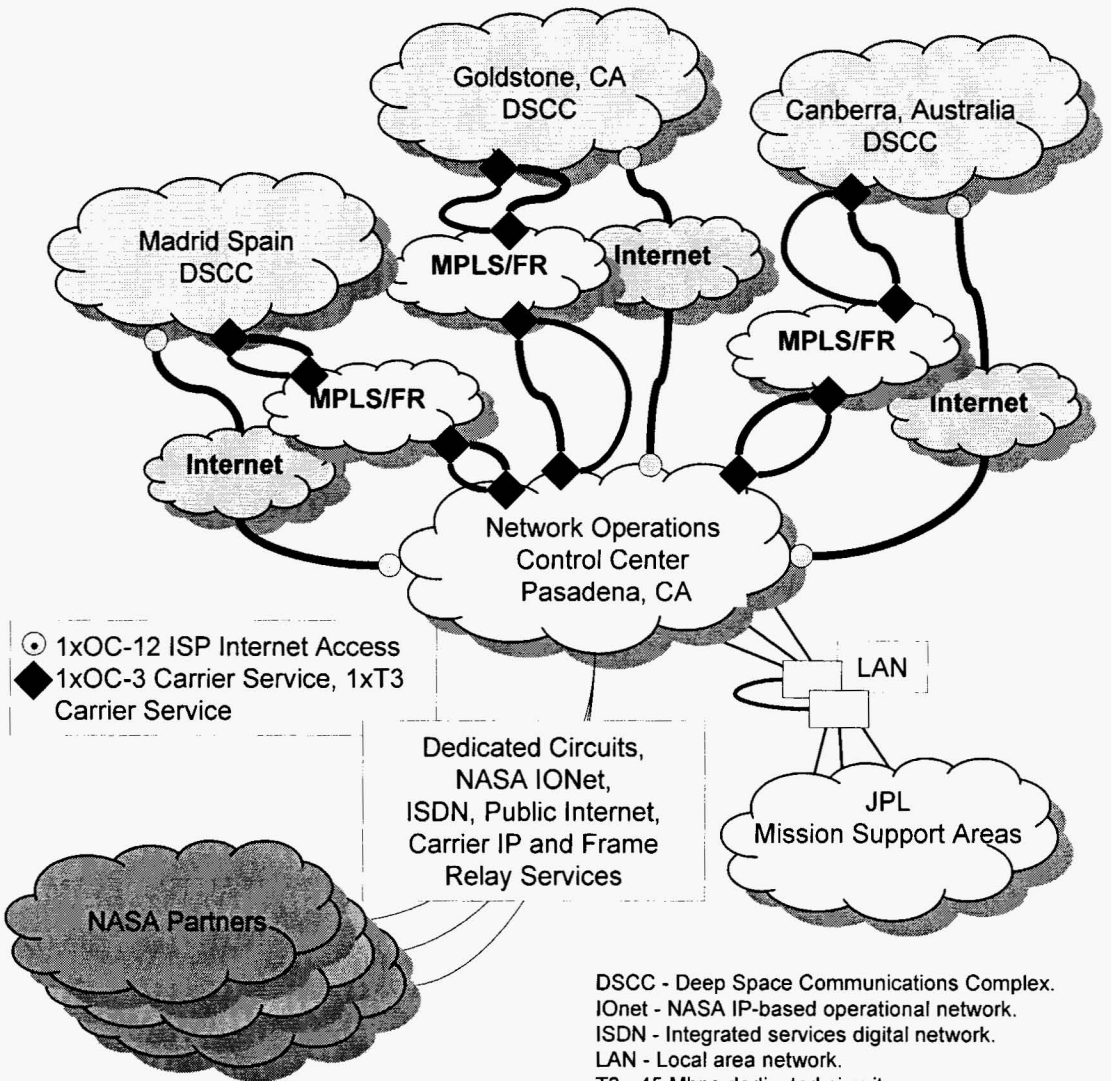
1 OC3 155 Mbps	$9.3 million/yr
1 T3 45 Mbps	$3.1 million/yr
OC-12 ISP 622 Mbps	$3.8 million/yr
Total	**$16.2 million/yr**

If dedicated circuits, ~$40.4 million/yr

Uncertainties

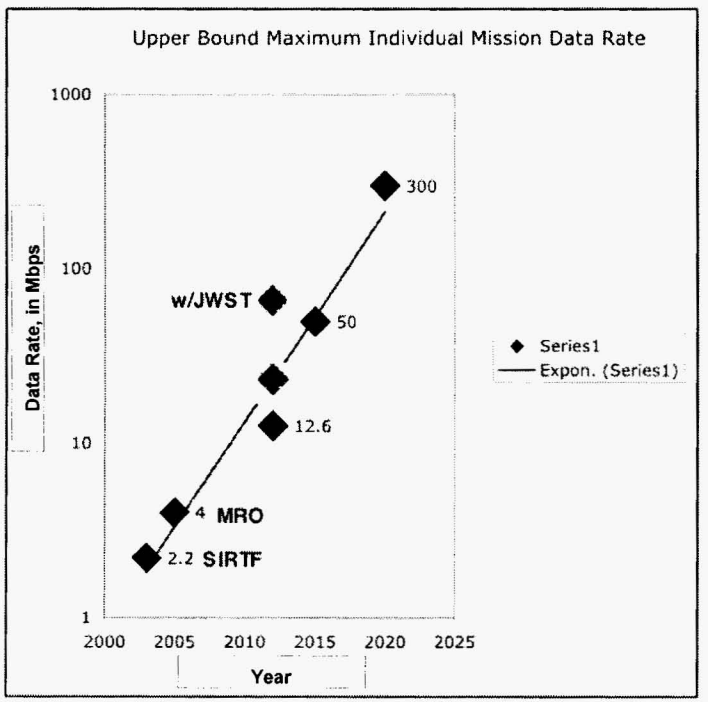
Support for JW Space Telescope, etc.

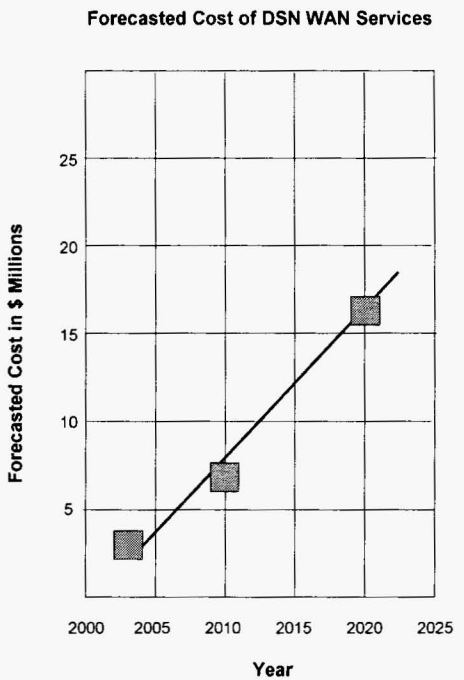
Effect of Planetary Area Network aggregation of multiple mission dataflows into single Earth-bound trunks.



DSCC - Deep Space Communications Complex.
IOnet - NASA IP-based operational network.
ISDN - Integrated services digital network.
LAN - Local area network.
T3 - 45 Mbps dedicated circuit.
OC-3 - 155 Mbps
OC-12 - 622 Mbps
QOS - Quality of Service

Forecast





Every ten years, DSN

- Bandwidth requirements increase 10X.
- NASA ground network costs increase 2X.

Infrastructure Uncertainties

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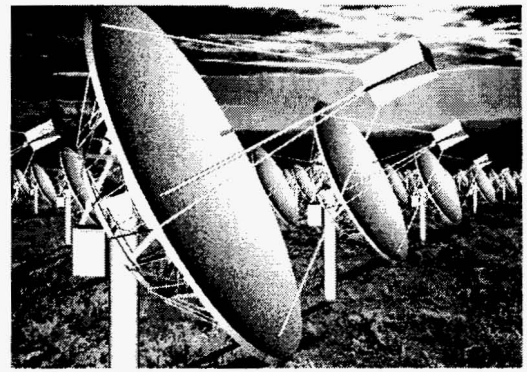
DSN Large Array

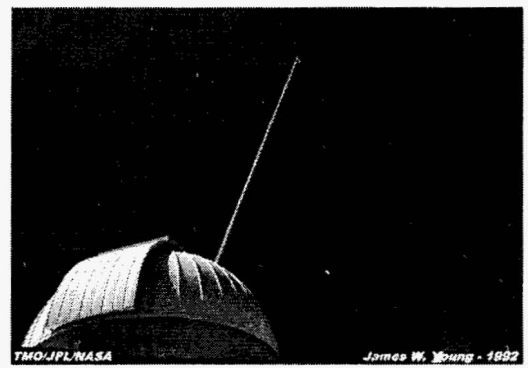
Characteristics

- Large number (~3600) of small (~12m) antennas, approximately equally distributed at approximately eight sites on each of three continents.
- **Very high speed dedicated path (~40 Gbps) from array location to DSCC.**

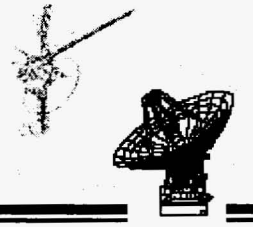


Optical Network

- **Characteristics**
- **Linear Dispersed Optical Subnet (LDOS)** - has seven stations equally spaced around the world.
- Elevation may range from 1,000 to 3,000 meters to be free from dust. Factors include geo-political realities: Oceans, unstable countries.
- **High-speed dedicated circuits from very remote locations to PIs.**



Conclusion



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Forecast

1. Voice and video transmission to VOIP/VIP by 2010.
2. Dedicated circuits to Public Internet for non-time sensitive data by 2010.
3. Dedicated circuits to Carrier Services such as frame relay and MPLS (class-managed services) for priority traffic by 2020.

Uncertainties

1. Very high rate missions (James Webb Space Telescope and iARISE), that may require acceleration of network development.
2. DSN infrastructure upgrades that include additional assets such as the DSN large array and optical networks.

Requires

- Continual prototyping/piloting program with emerging carrier services.