71683

TELEDESIC GLOBAL WIRELESS BROADBAND NETWORK: SPACE INFRASTRUCTURE ARCHITECTURE, DESIGN FEATURES AND TECHNOLOGIES

Dr. James R. Stuart
Vice President, Space Infrastructure

Teledesic Corporation, Kirkland, WA
(206) 803-1400, fax (206) 803-1404

NASA/Aerospace Corp. First International Conference on Integrated Micro-Nanotechnology for Space Applications

South Shore Harbor Resort and Conference Center, Houston, TX
30 Oct. - 2 Nov. 1995

Agenda

- Low Earth Orbit (LEO) Wireless Communications Revolution
- Teledesic 'Broadband LEO' Services and Network Features
  - Teledesic Corporate and Program Overview
  - Teledesic Services and Applications, Capacity, Coverage and Spectrum Usage
  - Teledesic Network and Architecture Features
- Teledesic Space Infrastructure Architecture and Design
  - Teledesic System/Subsytem Design Features and Key Technologies
  - Teledesic Space Segment Power, Mass, ΔV and Reliability Budgets
  - Teledesic Launch Campaign Features and Debris Mitigation
  - Teledesic Integrated Software and Distributed Control Features
  - Teledesic Constellation Control Operations and Ground Segment Features
- Industrial Impact of LEO Communications Revolution
  - New Service Providers and New Equipment Suppliers
  - Commercial Space Industry Impact
- Emerging Applications for the Shrinking Satellite Evolution
  - Possible Future with Hybrid Networks of GSO's, LEO's and HALE/UAV's
  - General Features of Ideal Micro/Nano-Satellite Networks
  - A Vision of Future Micro/Nano-Satellite Designs for Comm Networks

Teledesic

J.R.Stuart 10/29/95

Abstract: Teledesic represents a new paradigm for distributed space systems' design, production and operations. This paper will describe the Teledesic broadband services, applications, global network design and unique features of the new Teledesic space infrastructure, technologies and design approaches. The paper's introduction will discuss the wireless information revolution and the current 'Little' and 'Big' communications LEO's. The current technological and economic trends that drive us inevitably to higher frequency bands and much larger constellations (≥1000 satellites) will be briefly addressed. The Teledesic broadband network, services and architectural features will be described. Then the capabilities of the extremely high-performance and high-power Teledesic LEO satellites will be described (e.g., many kW's, 100's of MIPS, 1000 mps, 100's of beams, etc.).

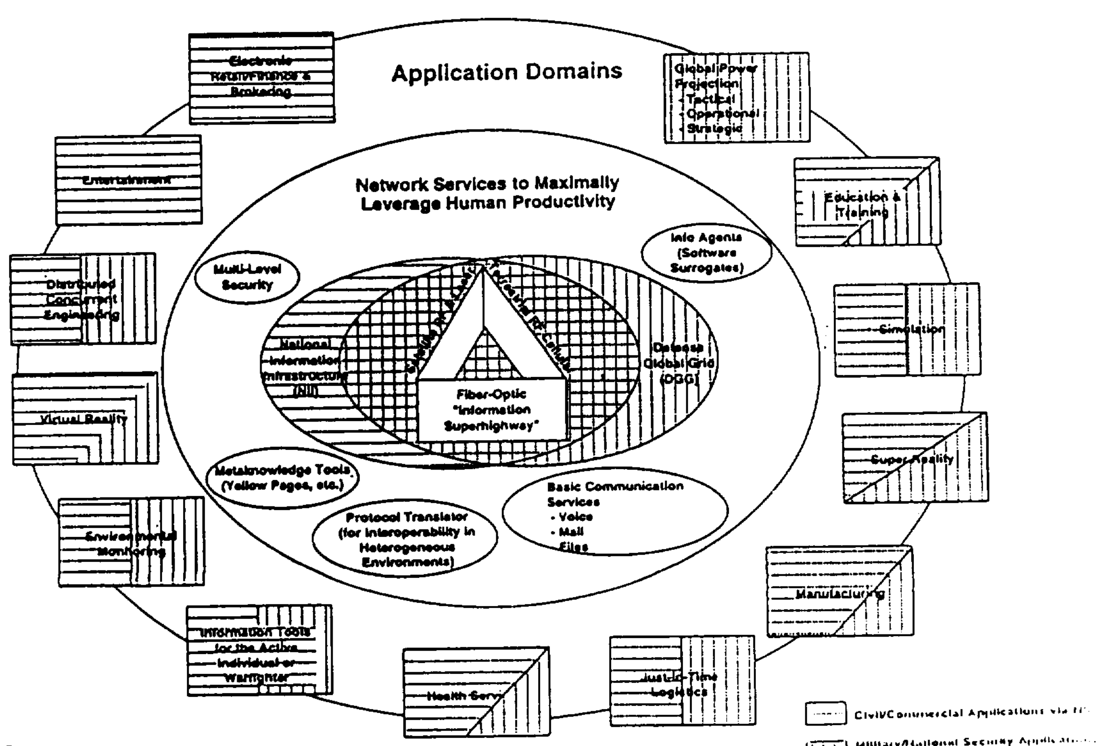
The Teledesic satellites are a new class of small satellites, which demonstrate the important commercial benefits of using technologies developed for other purposes by U.S. National Laboratories (e.g., Phillips, NRL, JPL, LeRC, etc.). The Teledesic satellite architecture, subsystem design features and new technologies will be described. The new Teledesic satellite manufacturing, integration and test approaches will also be addressed which use modern high volume production techniques and result in surprisingly low space segment costs. The constellation control and management features and attendant software architecture features will be addressed. After briefly discussing the economic and technological impact on the USA commercial space industries of the space communications revolution and such large commercial constellation projects, the paper will conclude with observations on the trends towards future systems architectures using networked groups of much smaller satellites.

Teledesic

Global Information Infrastructure (GII)

- GII is a Vision of a Universally Accessible Web of Multiple Interconnected Networks
  - Permitting Access to Widely Distributed Private/Public Data Bases
  - Providing Ready Transmission of Information (Voice, FAX, Text, Images, Video, etc.)
    - In Any Format - To Anyone - In Any Place - At Anytime
- GII is an Entire GII System:
  - Human Users (and Developers)
  - User's Information Appliances (Computing and Consumer Electronics)
  - Accessed Information, Data Bases and Computing Resources
  - Networks
- The GII Network Will Be an Intricately Tangled Web of Multiple Overlaid Networks
  - Wired and Wireless
  - Terrestrial and Space
  - Physical and Virtual
  - Private, Commercial and Government
- GII (and Large Evolving Commercial Market) Will Migrate to Efficient Web Elements:
  - Reliable, Ubiquitous, Seamless, Interconnected, Flexible, Cost effective
  - Successful Elements will be Interoperable:
    - 'Open' Interfaces with Accepted Standards
    - Wide Array of Competing Information Appliances and S/W Tools
      - Interoperable and Interchangeable by Design
      - Standard User-Friendly (Easy) Interfaces for H/W and S/W:
        (e.g. Discovery/Recovery Applications, Operating Systems , etc.)
    - Many Interchangeable Competing Service Providers and Equipment Suppliers

A Current View of LEOs Role in the National Information Infrastructure (NII)



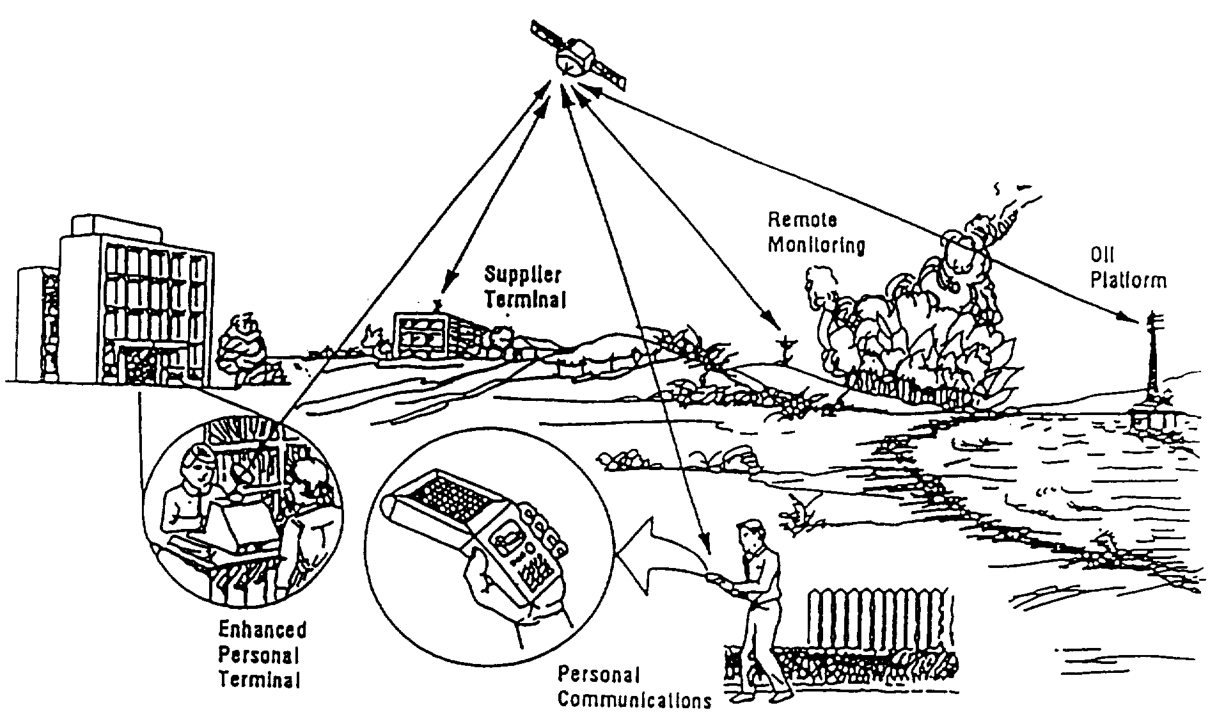
Source: Dr. Robert J. Bonometti (ARPA), Sept. '93

Low Earth Orbit (LEO) Wireless Communications Revolution

- LEO Communications Services Will Be Available Globally and Economically:
  - Voice and Broadband Data, Fixed and Mobile Services, Personal Communications FAX, E-mail, Messages, Monitoring, Alarms, Positioning, Tracking and Location
- Personal Ground Terminal Business Is Enormously Larger Than LEO Space Segments
  - LEO Constellations Enable This Much Larger 'Information Appliance' Business
  - Hottest New Personal Electronic Products Since PC's and VCR's Will Be:
    - Mobile Communicators, Wireless Modems, Pocket Videophones, etc.
- Shift from Last 30 Years of Satellite Communications Evolution:
  - Bigger, More Powerful, Longer Lifed Satellites
  - Hierarchical Point-To-Point Communications Architectures
- Biggest Advance In Satellite Communications In 30 Years:
  - Lightsats, Intersatellite Links, Distributed Networks, New Competitive Multiple-Choices, Interconnectivity, Interoperablity, Global Marketplace Determination of 'Best'
  - Global LEO MSS Com. Services: 800M$ in 1992 to 10B$ in 2002 (1993, NASA/NSF)
- Future Will Be <u>Networks Of Hybrid Systems</u> Connecting Everyone To Everyone
  - Overlaid Interconnected and Interoperable Networks
    - Terrestrial Wire, Cellular, Coaxial Cable, Fiber Optic Cable, etc.
    - GSO Large Satellites, and the New LEO, MEO and GSO Lightsats
  - Large, Competitive, Open, Diverse Global Markets
  - Multiple Service Approaches Will Become Available to All Customers
  - Continuous Evolution Of Most Effective Set of Communications Networks
    - 'One Size Fits All' is Victim to More Convenient 2nd-to-Market Choices
    - Bandwidth/Quality/Price/Convenience-On-Demand (Interoperable Choices)

Teledesic

Wireless Satellite Services on the Horizon



Teledesic

LEO Satellite Communications Systems Service Categories

- Mobile (MSS) "Little" LEO's (UHF, VHF)

  Noncontinuous Worldwide Coverage (Periodic to Near-Real Time Availablity)
  "Bent Pipe" and "Store-and-Forward"
  Gateways, PSTN Connections
  Modulations: FDMA/TDMA or CDMA

  Non-RealTime and Near-Real Time Digital Mobile Services (2.4 kbps - 9.6 kbps)
  Digital Messages, Alarms, Monitoring Data, Tracking, E-Mail, FAX, Paging, etc

  Typical Delivery Delay Times
  Within Footprint (~4000 km Diameter): ≤2-10 minutes
  International (e.g., USA-Europe): 30 minutes - 8 hours

  Typical Subscriber Costs
  Terminals: \$500-\$100 (as low as \$25 quoted for meter reading)
  Data: 1.0¢ -0.001¢ per byte

- Mobile (MSS) "Big" LEO's (L-Band)

  Continuous Worldwide Coverage (~ Cellular Dial-tone Availability)
  Either 'Bent Pipe' or via Intersatellite Links
  Gateways, PSTN Connections
  Modulations: TDMA or CDMA

  Local Cellular Company Size (largest: ~250,000 Subscribers at 0.1 Erlang)
  Real Time Mobile Services (~ 4.8 kbps): Digital Voice, Narrowband Data (<Toll Quality)

  Typical Long Distance Delay Times: ~Terrestrial Delays

  Typical Subscriber Costs
  Terminals: \$1000 -\$500 (and lower for RDSS only)
  Voice/Data: \$3.00 - \$0.50 per minute

  Typical Time and Cost to Send Daily NY Times (1 MB): 3.47 hours, \$60 to \$600

LEO Satellite Communications Systems Service Categories (Cont'd)

- Fixed (FSS) and Mobile (MSS) 'Broadband' LEO's (Ka-Band)

  Continuous Worldwide Coverage
    Terrestrial Dial-tone Availability
    Small, Earth-Fixed Cells
  Regional Bell Operating Company Size
    >20,000 simultanous T1 (1.5 Mbps) connections worldwide
  Intersatellite Links
  Gateways, PSTN Connections
  Modulation: FDMA/TDMA
  Real Time Interactive Services (16 kbps - 1.2 Gbps)
    Bandwidth On Demand
    Broadband Data, Video, Digital Voice, etc. (>Toll Quality, 10^{-10} BER)
    Typical Phone Company Services and Features
    Typical Long Distance Delay Times: < Fiber

  Typical Subscriber Costs
    Interface Units: \$10,000-\$1,000 (falling sharply with volume and competition)
    Data: Comparable to local PTT charges
  Time and Cost to Send Daily NY Times (1 MB): 5 sec., few cents (to ~local PTT charges)

'Little LEO' Satellite Communications Systems on the Horizon

- Mobile (MSS) "Little" LEO's (UHF, VHF)

FCC Construction License Granted

Orbital Communications Corp. (OrbComm)	36 Satellites,	40 kg,	4 year lifetime

FCC Construction License Pending (Experimental Licenses Granted)

Starsys Global Positioning, Inc. (Starnet)	24 Satellites,	125 kg,	5 year lifetime
Volunteers in Technical Assistance (VITA)	2 Satellites,	136 kg,	5 year lifetime

FCC Construction License Pending (2nd Round Applicants)

CTA Commercial Systems, Inc. (GEMnet)	38 Satellites,	45 kg,	5 year lifetime
E-Sat, inc. (E-Sat), USA	6 Satellites,	100 kg,	10 year lifetime
Final Analysis Comunication Services, Inc. (FAIsat) (Rec'd experimental lic. for 1 satellite)	26 Satellites,	100 kg,	7 year lifetime
GE American Communications (Eyetel)	24 Satellites,	15 kg,	5 year lifetime
Leo One USA Corp. (LEO ONE USA)	48 Satellites,	124 kg,	5 year lifetime
Orbital Communications Corp. (OrbComm) (Requesting 12 additional satellites)	48 Satellites,	40 kg,	4 year lifetime
Volunteers in Technical Assistance (VITA) (Requesting 1 additional satellite)	3 Satellites,	128 kg,	5 year lifetime

International 'Little LEO's' (in development/planning), e.g:

Leo One Panamericana (Mexico), ECO-8 (Brazil), Gonetz, Courier, Elekon (Russia), MiniSat(Spain), Safir (Germany), TAOS/S80T (France), Artes (Belgium), Leostar (ESA), KITCOM (Australia), etc.

Teledesic

'Big LEO' Satellite Communications Systems on the Horizon

- Mobile (MSS) "Big" LEO's (L-Band)

FCC Construction License Granted

Globalstar Telecommunications Ltd. (Gobalstar), USA
48 Satellites (+ 8 spares), 426 kg, 7.5 year lifetime, 1.6 B$

Iridium Inc. (Iridium), USA
66 Satellites (+ up to 12 spares), 700 kg, 5 year lifetime, 3.4 B$

Odyssey Worldwide Services, (Odyssey), USA
12 Satellites, 1952 kg, 12 year lifetime, 2.5 B$

FCC License Decision Deferred (Financial qualifications must be met by 1/96)

Constellation Communications, Inc. (ECCO), USA
46 Satellites (+ 8 spares), 500 kg, 6 year lifetime, 1.7 B$

Mobile Communications Holdings, Inc. (Ellipso), USA
16 Satellites, 500 kg, 5-7 year lifetime, 1.1 B$

American Mobile Satellite Corp., (AMSC), USA
12 Satellites, 3.1 B$

+ International 'Big LEO's' (in development/planning), e.g:

·Inmarsat P, UK (10 Satellites, 2.6 B$, 1.4 B$ committed), Russia, France, China, etc.

Teledesic

'Broadband LEO' Satellite Communications Systems on the Horizon

- Fixed and Mobile (FSS/MSS) Broadband LEO's (Ka Band)

Teledesic Corporation (Teledesic), Kirkland, WA, USA

Partners:	Craig O. McCaw, William H. Gates III, McCaw Cellular Communications (AT&T)
Constellation:	840 Satellites (21 polar orbits at 700 km altitude) (+ 84 in-orbit spares)
Satellite Mass, Lifetime:	800 kg, 10 year
Primary Market:	Rural and remote parts of the world that would not be economic to serve through traditional wireline means
Typical User:	Educational institutions, government agencies, health-care and industrial/commerical organizations, and people in remote areas
Typ. Cost per Minute:	Comparable to local PTT charges (includes PSN charges for local, long-distance, Int'l tails)
Initial Interface Unit Cost:	$10,000-$1,000 (falling sharply with volume/competition) (Standard Terminals, 16 kbps to 2 Mbps) ('Gigalink' Terminals, 155 Mbps to 1.2 Gbps)
Total System Cost:	9 B$
Communications:	Satellite switching (FDMA/TDMA)
FCC Status:	FCC Filed 3/94 (FSS), Ammendment 12/94 (MSS)

Teledesic

Teledesic Corporation Background and Status

- Teledesic Company Background
  - Founded in June, 1990
  - Concept Originally Developed (reduced to writing) in 1988
  - Headquaters: Kirkland, WA
- Corporate Mission Statement:

> "Teledesic seeks to organize a broad, cooperative effort to bring affordable access to advanced information services to rural and remote parts of the world that would not be economic to serve through traditional wireline means."

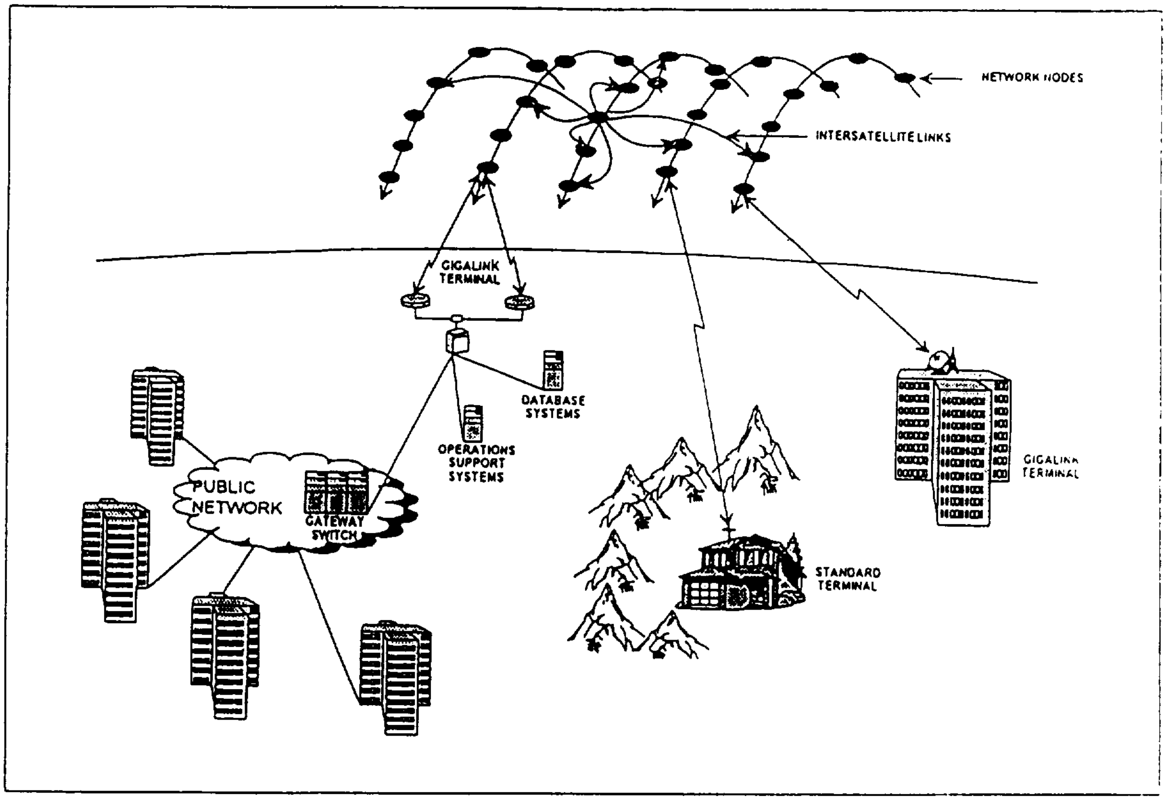
- Teledesic Shareholders

Craig O. McCaw (Founder - McCaw Cellular Communications)	32%
William H. Gates III (Founder - Microsoft)	32%
McCaw Cellular Communications (AT&T)	24%
Others	12%

- Teledesic Status
  - Feasibility Study and Point Design (Phase A) Completed
    - > 5 Years by Extraordinary Team of Full-time Employees, Consultants, and Subcontractors
  - FCC Application Filed 3/94 (FSS) and Ammendment Filed 12/94 (MSS)
  - Currently in Pre-Phase B (Planning and Development)
    - Regulatory Process Support
    - Program Planning and Organizational Development
    - System Requirements Update and Technologies Assessment
    - Key Supplier/Partner Candidates Identification and Selection

Teledesic

Teledesic Network Overview



Teledesic Services and Applications

- Provider (Wholesale) of Telecommunications Services to 'In-Country' Distributors
  - Interactive 'Network-Quality' Voice, Data, Video, Multimedia, etc.
  - Bandwidth-on-Demand
    - 16 kbps to 2 Mbps (Standard Terminals)
    - 155 Mbps to 1.2 Gbps ('Gigalink' Terminals)
- Switched and Point-to-Point Connections
- Connections Via Gateways to Terminals on Other Networks
- Teledesic Service Quality
  - Comparable to Modern Urban Network
  - 'Fiber-Like' Delays
  - 16 kbps Basic Channels (Support 'Network-Quality' Voice, Data, etc.)
  - 1.5 Mbps Channels (Support 'Network-Quality' Data, 'VCR-Quality' Video, etc.)
  - 1.2 Gbps Channels (Support 'Fibre-Quality' Broadband Applications)
  - Bit Error Rates $<10^{-10}$
  - High Link Availability (Comparable with Urban Terrestrial Networks)

Teledesic Capacity, Coverage and Spectrum Usage

- Teledesic Network Capacity (Note: Actual user capacity depends on average channel rate and usage)

  Standard Terminals (16 kbps to 2 Mbps)

  >23 Mbps (standard terminal) capacity within Teledesic 53 km x 53 km Cell

  >20,000 simultanous T1 (1.5 Mbps) connections worldwide

  'Gigalink' Terminals (155 Mbps to 1.2 Gbps)

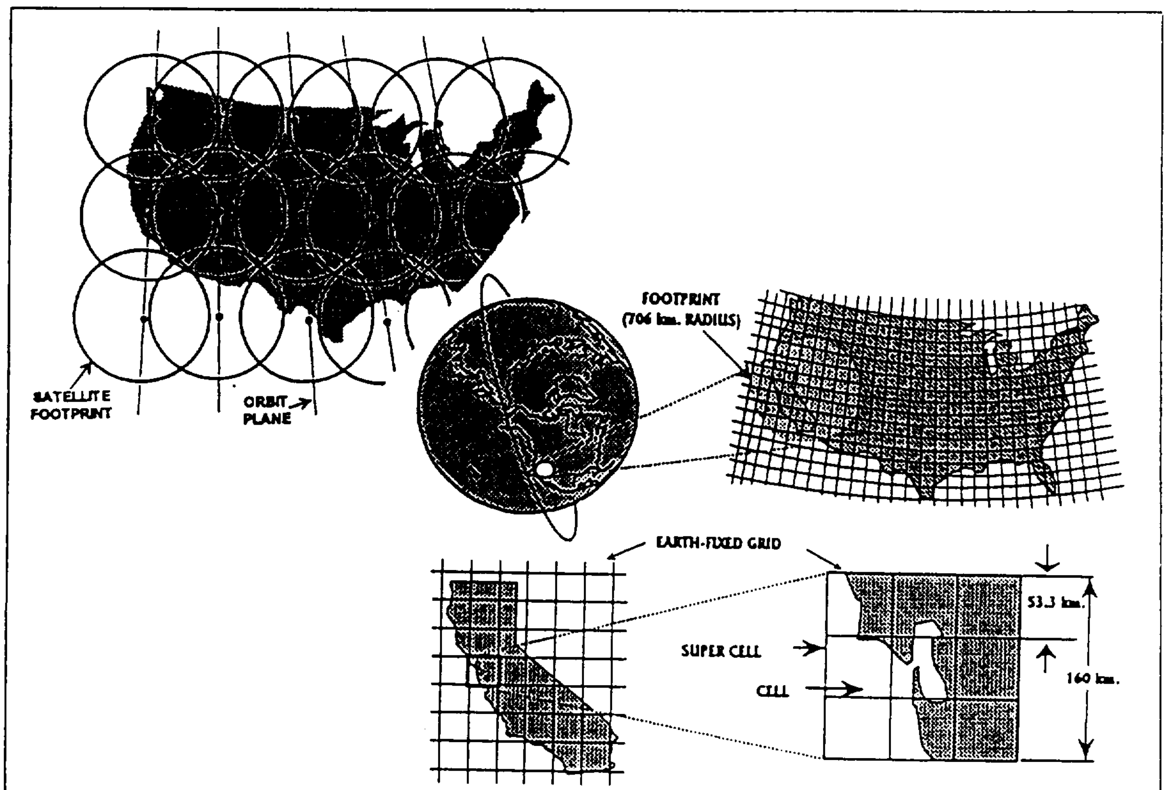
  16 steerable 'Gigalink' spots within Teledesic 1400 km diam. Footprint

  >8,000 simultanous 'Gigalink' connections worldwide

- Teledesic Network Handles Wide Variation in Channel Rates and User Densities
- Teledesic Network Grows 'Gracefully' to Much Higher Capacity
- Teledesic Spectrum Resource Bandwidth Requirements

Standard Terminal Uplink (Bandwidth):	500 MHz
Standard Terminal Downlink (Bandwidth):	500 MHz
Gigalink Terminal Uplink (Bandwidth):	800 MHz
Gigalink Terminal Downlink (Bandwidth):	800 MHz
Intersatellite Cross Links (Bandwidth):	2000 MHz

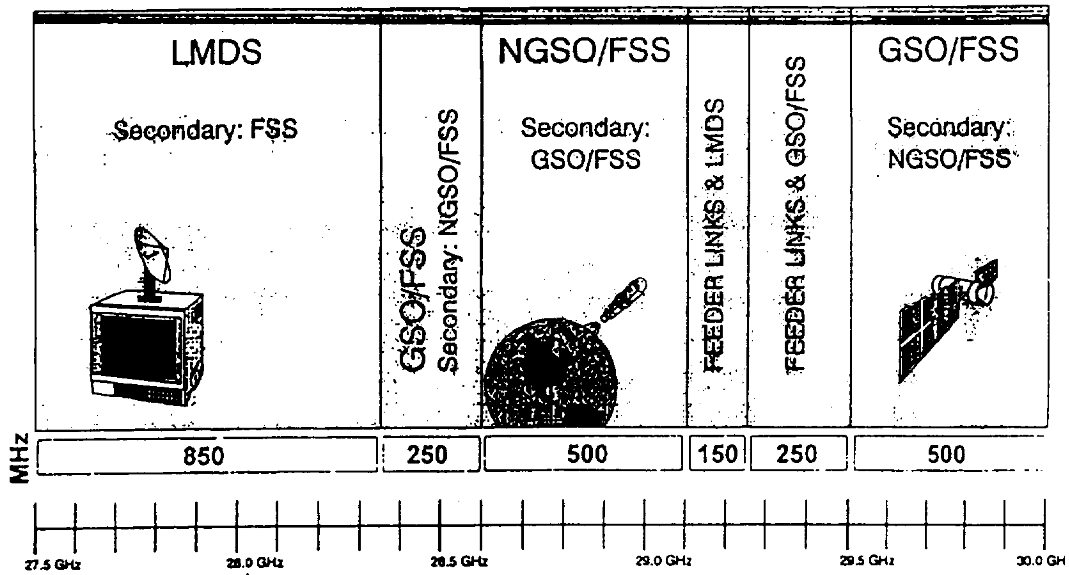
Teledesic Footprint and Cell Features



FCC Notice of Proposed Rulemaking (NPRM), 13 July 1995

- Proposed NGSO Allocation Can Accommodate Teledesic

  500 Mhz: Primary for Broadband LEO Service (NGSO)
  750 Mhz: Secondary for NGSO



Source: FCC (NPRM, 7/13/95)

Teledesic

J.R.Stuart 7/17/95

'Broadband GEO' Communications Systems on the Horizon

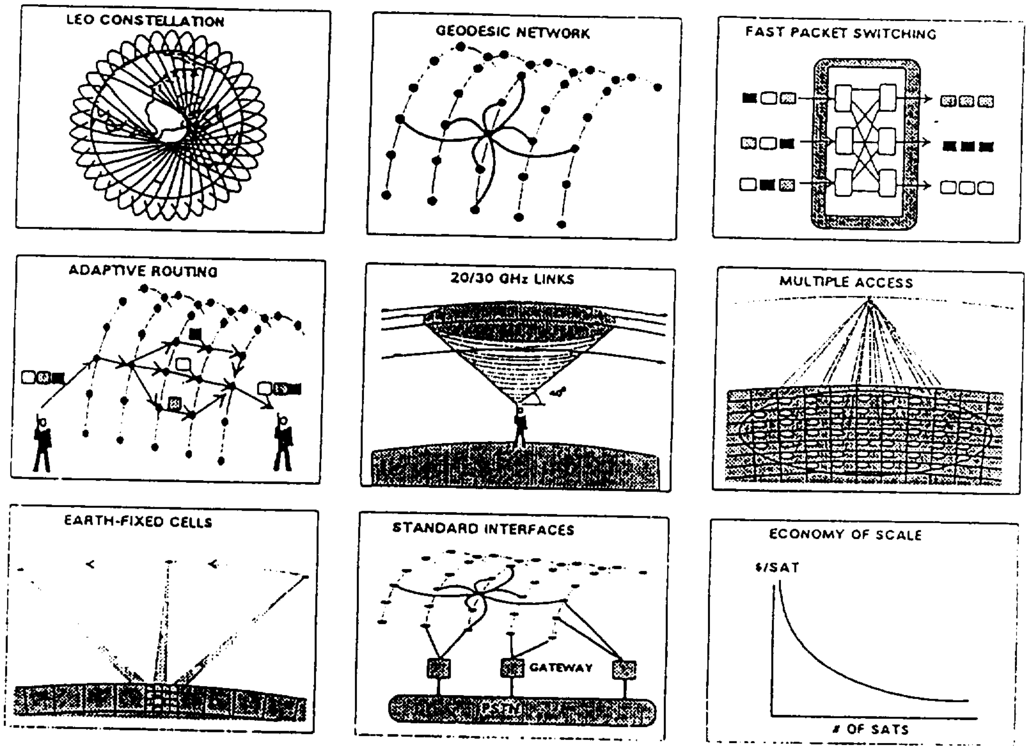
- Broadband GEO Fixed (FSS) (Ka Band)

<u>FCC License Applicants</u>

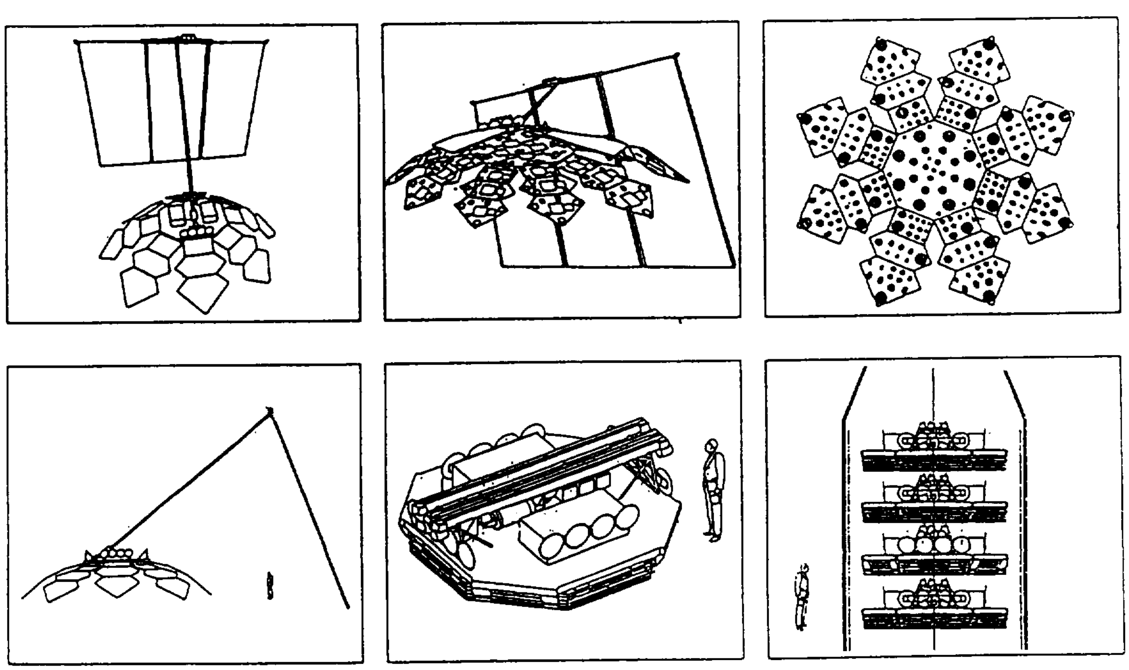
AT&T (Voicespan), USA	12 Satellites
EchoStar (EchoStar), USA	2 Satellites
GE Americom (xx), USA	9 Satellites
Hughes (Spaceway/Galaxy), USA	15 Satellites
KaStar (KaStar), USA	1 Satellite
Lockheed (AstroLink), USA	9 Satellites
Loral (CyberStar), USA	3 Satellites
Motorola (Millenium), USA	4 Satellites
NetSat 28 (xx), USA	1 Satellite
PanAmSat (PanAmSat),USA	1 Satellite*

Teledesic

Teledesic Broadband LEO Network and System Features



Teledesic Satellite Configuration Features



Teledesic Space Segment Key Features

- Modern, High Performance, High Power, Mass-Producible Satellite System
  - Identical 3-Axis Stabilized Satellites for All Constellation Positions
  - High Performance, High Reliability, 10 year Lifetime Satellite System
    - High Power (>6.6 kW EOL, >300AH, 15 kW surge capability)
    - High Computational Power (>300 MIPs, >2 Gbytes RAM)
    - High ΔV Low-Thrust Propulsion (>1000 mps)
    - Lightweight (795 kg)
    - Compact Launch Configuration (3.1-3.3 m diameter x 2 m height)

- Design Features Tailored Specifically for Large Constellation
  - High Volume Production of Components
    - Large Economies of Scale
  - Automated Integration and Test of Satellite Systems
    - On-Board Test S/W
    - Autonomatic On-Orbit Health Monitoring and Constellation Control
  - Self-Stacked, Self-Deployed Group Launch by Variety of Launchers
    - Multiple International Launchers and Launch Sites
    - Assembly Facilities at Launch Sites
  - Automatic Orbit Transfer, Insertion and Gap-Filling
  - Active On-Orbit Spares with Routine Block Replenishments
  - Reliable End-of-Life Disposal/Deorbit Capability

Teledesic

Teledesic Space Segment Key Technologies

Baseline Modern Space Technologies	Technology Back-ups	Enhanced Technology Alternatives
Power		
CIS Thin Film Solar Array (Copper Indium Diseleinide, 6% EOL)	Crystal Si, Crystal GaAS Multi-junction, Concentrators	Thin Film CdTe (6% EOL) Thin Film CIGS (8% EOL) Poly-, Amorphous-Si
NH2 (CPV) Batteries (6x60 AH)	NH2 (IPV) Batteries NH2 Batteries NiCad Batteries	Sodium Sulphur Batteries Lithium Ion Batteries Thin Film Polymer Batteries Flywheels (Lightweight, Long-life)
High Voltage Distribution System	28 VDC (DET)	AC Distribution
Propulsion		
Pulse Plasma Electric Thrusters (0.7 mN, 60 kN-s,1200 Isp)	Hall SPT Thrusters (80mN) Arc-Jets	Deflagration Thrusters Zenon Thrusters
Mechanisms		
Shape Memory Solar Array Extension Booms	Bistem Booms Cont. Longeron Booms	Inflatable Solar Array Booms
Paraffin (HOP) Latch/Deploy Mechanisms	Motors, Spring/Dampers	Shape Memory Mechanisms
Vibration Isolation (Passive)	Tuned Static Attachments	Embedded Active Piezo Electrics
Structures		
Advanced Composite Structures	Standard Composites Aluminum	Smart Structures Integrated Cabling/Thermal

Teledesic

Teledesic Space Segment Key Technologies (cont'd)

Baseline Modern Space Technologies	Technology Back-ups	Enhanced Technology Alternatives
Attitude Determination and Control		
Lightweight IFOG IMU's	RLG, QRS IMU's	DQI IMU's
Long-Life Reaction/Momentum Wheels	Multiple Back-up Wheels	Magnetic Suspension Wheels
Data Handling/Electronics		
High Perf. Rad Hard Microprocessors (PC603)	RS3000/6000, 68020	PC604, Pentium, etc.
Optical LAN Data Bus	1773 LAN Data Bus	High Perf. Optical LAN Bus
SC-cut Crystal Oscillators	AT-cut Crystal Oscillators	- -
GaAs A/D Converters	ECL A/D's	CMOS A/D's
GaAs VLSI Digital Signal Processors	ECL DSP's	CMOS DSP's
GaAs Fast Packet Switches	ECL FPS's	CHFET, Optical FPS's
Multi-chip (MCM) Packaging	Advanced Hybrids	UHDI, 3-D Packaging
Software		
Automated Prod., Ass'y, Test, On-orbit Ops S/W	Partially Automated S/W	Autonomous IA&T/COCC S/W
Communications		
PHEMT GaAs MMIC's: HPA's and LNA's	HBT MMICs	InP MMICs
20/30 GHz Phased Array Antennas	Gimballed Arrays/Reflectors	Multi-Beam Lens
60 GHz Intersatellite Phased Arrays	Gimballed 60 GHz Reflectors	Optical Intersatellite Links

Teledesic

Teledesic Satellite Resource Budgets

SATELLITE SUBYSTEM RESOURCE BUDGETS	Mass Kg	Power Average W	Volume cm3	Reliability %
Structure	87 kg	0 W	9,846 K cm3	99.9986 %
Mechanisms	52 kg	0 W	1,139 K cm3	95.3037 %
Cabling	22 kg	0 W	8 K cm3	99.9996 %
C&DH/TT&C	9 kg	8 W	11 K cm3	98.8493 %
Temperature Control	37 kg	24 W	153 K cm3	99.9990 %
Attitude/Orbit Det. and Control	12 kg	19 W	51 K cm3	96.6997 %
Propulsion	60 kg	0 W	250 K cm3	99.9999 %
Power	239 kg	2288 W	85 K cm3	98.9488 %
Communications Payload	144 kg	3000 W	3,557 K cm3	80.0488 %
Contingency (20%)	132 kg	1068 W	3,020 K cm3	-
SATELLITE SYSTEM:	795 kg	6,407 W	18.1 m3	72.2 %

Component Volume Inside Satellite Bus (3): 0.553 m3
Bus Fill Factor: 25%

Teledesic

Teledesic Satellite Propulsion ΔV Budget

PROPULSION ΔV BUDGET (10 yr)	Velocity Increment m/s
Orbit Transfer and Insertion	272 m/s
Orbit Drag Maintenance	47 m/s
Sunsync. Orbit Maintenance	30 m/s
Gap-Filling Maintenance	87 m/s
Deorbit Retro Maneuver	65 m/s
Contingency (20%)	100 m/s
TOTAL ΔV REQUIREMENT:	601 m/s
Total ΔV Capability	1010 m/s
TOTAL ΔV MARGIN (68%):	409 m/s

Teledesic

Teledesic Constellation Deployment

- Diverse Set of International Launchers (and Launch Sites) Baselined
  - Launch Site Throughput Capacity Assured
    - 973 satellites Launched in 24 months
    - ~1 Launch per Month from 4-6 International Launch Sites (~6 Pads)
    - Multiple Satellite Stacked Launches
  - Avoids Single-Point Interruptions (Launcher, Launch Site)
    - Launcher Production Problems
    - Launch Delays
    - Launch Failures
  - Assures Stable Launcher Supply (Capacity)
  - Assures Stable Launcher Economics (Competition)
- > 30 Viable International Candidate Launchers Identified
  - Expected Phase B Design Results:
    - Satellite Stowed Dimensions: 3.1-3.3 m diam x 2 m
    - Satellite Launch Mass: 800 kg
    - Stack Dispenser/Tug (1100 kg, 3.1-3.3 m diam x 2 m)
- Initial Deployment and Replenishment
  - Initial Launch of 973 Satellites
    - 840 Satellites — Constellation On-Orbit
    - 84 Satelltes — On-Orbit Active Spare Satellites
    - 49 Satellites — Launch Failure Margin
  - Routine Replenishment of 195 Satellites
  - Autonomous Deployment, Orbit Raising and Positioning
    - Injection by Dispenser/Tug ~600km, Near-Polar
    - Low Thrust Spiral to Final Orbit (700km)
    - Drift to Adjacent Orbit Planes (12-16 weeks), as required

Teledesic

Teledesic Debris Mitigation

- Teledesic Mangement is Committed to Debris Mitigation

  Early Establishment as Top Level Design Requirement
  Long Term Self Interest

- Teledesic Debris Mitigation Requirements

> Risk of Teledesic generated debris on Teledesic constellation and other Space Assets must be small compared to risk from ambient debris environment.

- Teledesic Debris Mitigation Actioins

  Early Establishment Unique Government/Industry Debris Experts for Debris Mitigation Analyses and Trades

  Air Force Phillips Lab, The Aerospace Corp.
  Lockheed-Martin, Orion Int'l, Teledesic

- Completed Phase 1 of Two Phase Study

  Phase 1 focus: establish environments and requirements
  Phase 2 focus: formulate design rules and validation methodology

- Completed NASA/JSC Review of Phase 1 Study Results (29-30 Sept. 1994)

> " Teledesic debris mitigation policy of limiting and managing the generation of debris to less than background is achievable."

IAF paper (IAA-94IAA.6.2.702 (12 Oct 1994)
Teledesic Debris Mitigation Phase 1 Study Report (Lockheed-Martin, Apr 1995)

Teledesic

Teledesic Ground Segment Key Elements

- Terminals

Standard Terminals:	16 kbps to 2 Mbps
'Gigalink' Terminals:	155 Mbps to 1.2 Gbps
COCC, NOCC, SPAC Gateways	155 Mbps to 1.2 Gbps

- Network Operations and Control Centers (NOCC)

  Redundant Facilties, providing e.g.,
  - Feature Processors
  - Network Management
  - Subscriber and Network Databases
  - Global Administration and Billing Systems

  Owned and Operated by Teledesic

- Service Provider Administration Centers (SPAC)

  Redundant Gateway Antennas

  Regional Administration, Billing Systems and Regional Network Control

  Owned and Operated by Service Provider

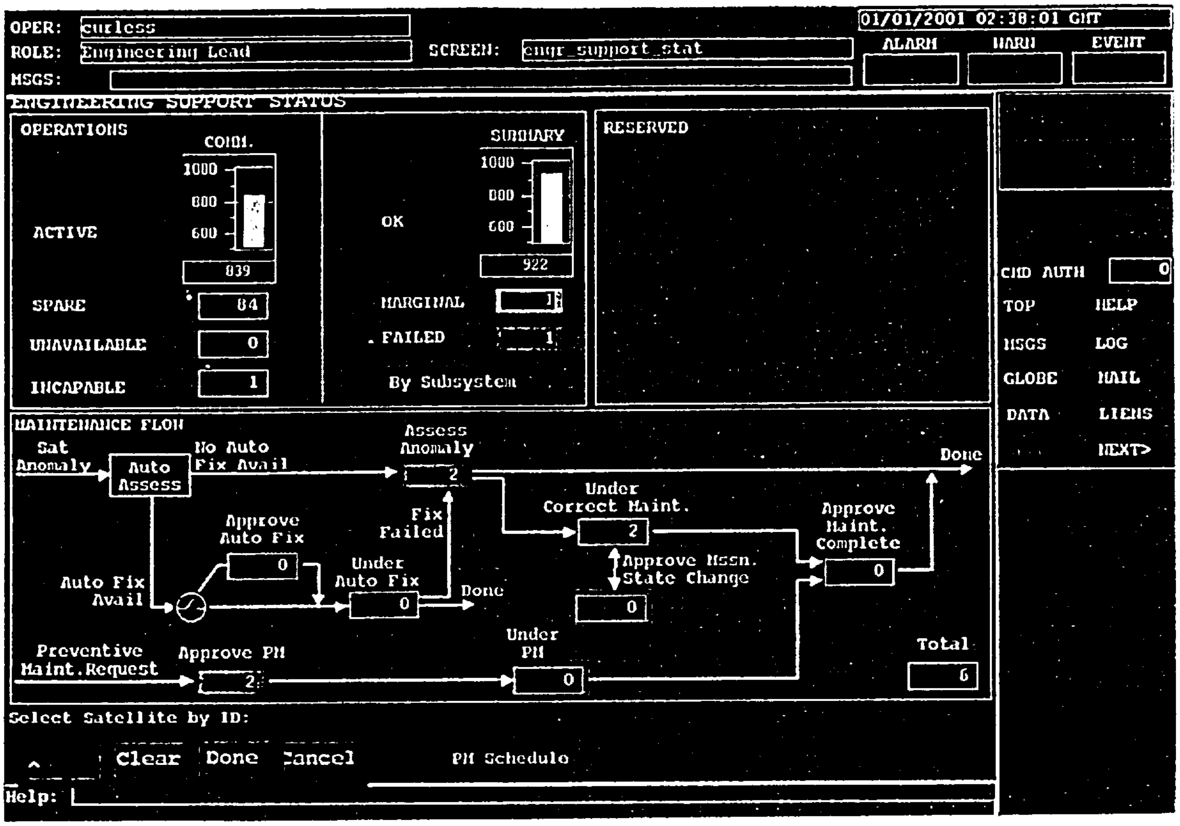
- Constellation Operations and Control Centers (COCC)

  Redundant Facilties for 4 Teams
  - Health Monitoring/Failure DetectionTeam ('Front Room')
  - Diagnostic/Failure Isolation Team ('Back Room')
  - Disposal/Deorbit Team ('Back Room')
  - Launch/Initialization/ReplacementTeam ('Back Room')

  Owned and Operated by Teledesic

Teledesic

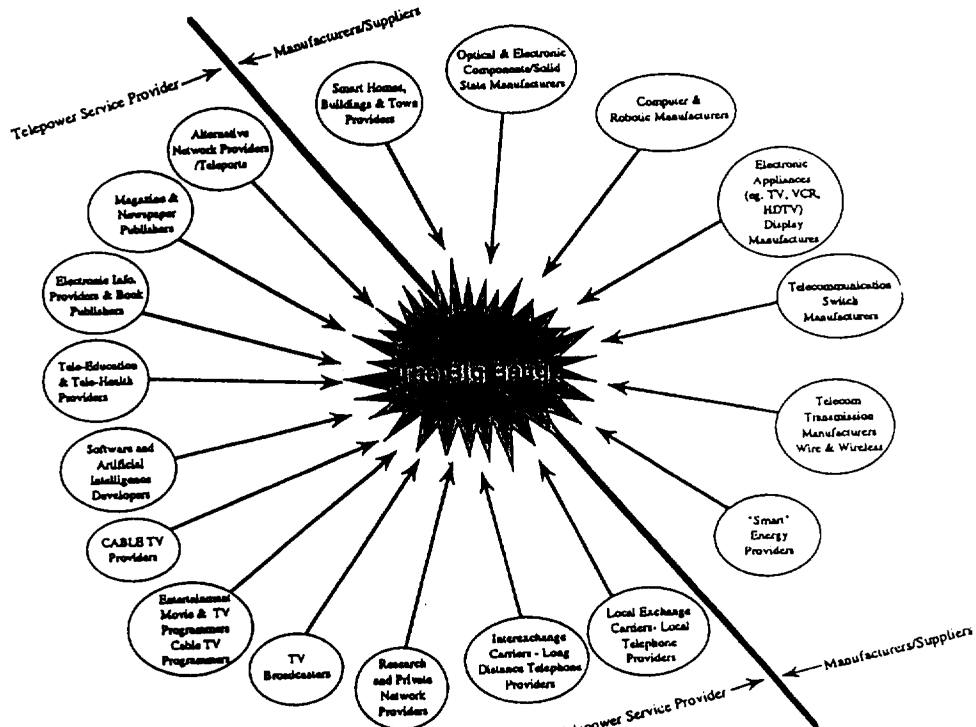
Teledesic COCC Display Example



Large LEO Projects Will Stimulate the Commercial Space Industry and Global Competitiveness

- Global Information System Infrastructure
  - Wireless Bandwidth on Demand (16 kbps to 1.2 Gbps)
- Space Communications Technology
  - 20/30 GHz Phased Arrays, GaAs Receivers/Transmitters
  - 60 GHz or Optical Gigabit Intersatellite Links (>1 Gbps)
  - Gigabit Modems and Multi-Gigabit Packet Routing
- Low Cost, High Capacity User Terminals (rates up to 1.2 Gbps)
- Volume Satellite Component Production, e.g.
  - 10 Million Watts of Solar Cells
  - 300,000 Amp-hours of Batteries
  - 24,000 Gigabits Modems
  - 8,000 Electric Thrusters
  - 8,000 Gigabits Crosslinks
  - 3,000 Space Computers (with Peripherals)
- Automatic Satellite Production, Assembly, Test and Constellation Operations
  - State-of-the-Art Software Engineering Techniques
  - Production, Assembly, Test and Operations S/W
    - Standard Operating System with Applications (3rd Party)
- Robust Launch Campaign
  - 1 Million Kilograms to Low-Earth Orbit

Wireless Revolution in New Service Providers and New Equipment Suppliers



Source: Dr. Joseph Pelton (CU), Feb. '94

Teledesic

Emerging Applications for Smaller (Light-, Micro- and Nano-) Satellites

- Current revolution in size and capabilities of space components and systems
  - Driving from Lightsats (100's-10 kg) to Microsats (10-1kg) to Nanosats (<1 kg)
- Shrinking satellites' attributes (small, light, focussed, high performance, quick development, producibility, distributed control, high-tech front-end investments, etc.) causing fundamental changes in choices:
  - New space systems capabilities, affordability and availability
  - New Industry structure and business approach
  - New technologies expand marketplace, applications, opportunities
- New space applications within reach of unprecedented number of people, e.g.:
  - Scientists, battlefield commanders, farmers, businessmen, researchers, etc.
- Difficult to predict market by extrapolating from 'mainframe' satellite experience
  - e.g., Apple couldn't foresee spreadsheets while developing Apple II
  - <u>New unforeseeable powerful applications undoubtedly coming</u>
- 5 early markets for increasingly smaller satellites apparent now:
  - Space science research
  - Environmental monitoring
  - Tactical military applications
  - Technology testbeds
  - <u>Communications</u>
    - Commercial space dominated by sat comm goods/services
    - Evolutionary sat comm improvements over past 30 years
      - 1000 times more cost effective
      - 100 times higher power
      - 50 times higher frequency use efficiency
      - 10 times longer lifetimes

USA Satellite Communications Technology 'Firsts'

First satellite with broadcast transmission capability from space (SCORE) -- 1958
First teletype relay by satellite (Courier 1B) -- 1958
First passive communications satellite (ECHO) -- 1960
First active communications satellite (Telstar) -- 1962
First communications satellite to transmit TV worldwide (Relay) -- 1962
First geosynchronous communications satellite (Syncom II) -- 1963
First operational military communications satellite (IDSCS) -- 1965
First operational commercial communications satellite (INTELSAT I, "Early Bird") -- 1965
First communications satellite capable of multiple access transmissions (INTELSAT II) -- 1967
First satellite to provide UHF mobile communications (TACSAT) -- 1968
First satellite with a despun antenna (INTELSAT III) -- 1968
First satellite with high-power spot-beam antennas (INTELSAT IV) -- 1971
First communications satellite to achieve frequency reuse (INTELSAT IVA) -- 1975
First communications satellite to provide commercial mobile satellite services (MARISAT) -- 1976
First complex hybrid communications satellite capable of operating in multiple frequency bands with multiple frequency reuse (INTELSAT V) -- 1980

Source: ITRI NASA/NSF Panel Report on Int'l Satellite Communications, 7/93

A Conservative Projection of the Annual Communications Service Business for the Next Decade

SATELLITE SERVICE	1992	2002
Fixed Satellite Services		
o INTELSAT	$4.5 billion	$8.5 billion
o Regional and Other International Sat. Systems	1.8 billion	3.6 billion
o U.S./Canada Nat'l Systems	2.3 billion	4.5 billion
o Other National Systems	1.4 billion	3.4 billion
Fixed Satellite Service (Total)	$10.0 billion	$20.0 billion
Mobile/Low Orbit Services	$0.8 billion	$10.0 billion
Broadcast Satellite Services	$0.5 billion	$8.0 billion
Military Satellite Services	**	**
Other (e.g., Data Relay, etc)	$0.1 billion	$0.3 billion
Total Services	$11.4 billion	$38.3 billion

* Table: does not include equipment sales (e.g., satellites, launch vehicles, ground stations, etc.), which were about $5 billion in 1992, and are predicted to double in the next decade.

** No accurate or meaningful figures for military services are readily available.

Source: Pelton, Edelson, Helm (ITRI NASA/NSF Panel Report on Int'l Satellite Communications) 7/93

Space Communications Today

- Space Communications is a Big Business
  - First and Still the Only Big Commercial Pay-off in Space
  - 160 Countries and Territories Involved with GSO Systems
    - >100 Satellites in GSO
    - > 20 Operational International, Regional and National Systems
  - 10 Countries have Significant Satellite Communications Industry Capabilities
    - > 10 B$/year in Revenues from Space Communications
    - > 5 B$/year Equipment Market (Satellites, ELV's, Terminals, etc.)
- US has Dominated the Space Communications Business for Past 25 Years
  - R&D from NASA and DOD Played Key Role in USA Satellite Communications Industry Development
  - USA Lead the World in Satellite Communications Technology Development
- Satellite Communications Business is Changing Fast and about to Explode
  - Global Market will Expand Rapidly into Personal Communications
  - Large Economic and World Power Stakes are Involved for Dominant Nation(s)
- USA Leadership (Technological and Economic) is Being Challenged
  - Over Past 2 Decades Many Other Nations have Invested Heavily Sat Com R&D
  - Dominant Role Played by USA in Past 25 years is Clearly Now Over
  - Engaged in Global Competition for Dominance (Technological and Economic)

Trends to Micro/Nano-Satellite Networks

- Commercial space dominated by sat Communications goods/services
  - Evolutionary GSO sat comm improvements over past 30 years
    - 1000 times more cost effective
    - 100 times higher power
    - 50 times higher frequency use efficiency
    - 10 times longer lifetimes
  - LEO's and HALE's will be next revolution in communicaitons
    - Shrinking size and distance to user
  - Nano-satellites in clusters and constellations will be following wave
    - Distributed, networked/interlinked, virtual missions
    - Driven by comms (and remote sensing) applications
- Bandwidth, Availability, Interoperability and Mobility will drive future comms
  - Small user terminals require high power <u>or</u> large apertures on satellite
  - Low power, distributed, large aperture, interlinked network of nano-sats
- General Features of Ideal Micro/Nano-Satellite Networks
  - Low-Cost, Disposable, Low Power Highly Efficient Nodes
  - Large, Distributed Aperture, Small Steerable Beams
  - Capable Inter-satellite links with precision position determination
  - Reliable Distributed Control and High Autonomy
  - Shared Mu.ti-Network Operating Systems and Interoperable Control
  - etc., etc...
- A Vision of Micro/Nano-Satellite Designs for Comm Networks

Teledesic

Biography: Dr. James R. Stuart is the Vice President, Space Infrastructure for Teledesic Corporation (a global, wireless, broadband, LEO network), and has been an independent, international consultant specializing in advanced commercial space systems. He has layed an important role in the creation and development of LEO and GSO communications lightsats, and is currently an active principal and board member in several entrepreneurial technology and space companies involved with communications satellites and small launch vehicles. Dr. Stuart also acts as Chief Technical Advisor for two 'Little LEO' store-and-forward programs (a licensed Mexican constellation, and a recently filed U.S. constellation). Dr. Stuart previously held positions as Chief Scientist and Chief Engineer at Ball Space Systems Division in Boulder, CO. He was also founding Chief Engineer of Orbital Sciences Corporation, Assistant Laboratory Director of the Laboratory for Atmospheric and Space Physics, and creator and first Project Manager of the Mars Observer Project at NASA/Jet Propulsion Laboratory, where he was also Manager of Advanced Planetary Programs. Dr. Stuart has been on various graduate faculties of the University of Colorado at Boulder for over 15 years: in the Electrical Engineering, Telecommunications and Aerospace Engineering Sciences Departments, as well as in the Center for Space Construction. He received his Ph.D. in Systems Engineering (1979), M.S. in Operations Research (1977), and M.S. in Electrical Engineering (1974) from the University of Southern California, and his B.S. in Physics (1968) from the University of Washington. Dr. Stuart has received numerous professional awards, including NASA's Exceptional Service Medal for his project management of the Solar Mesosphere Explorer Project, JPL's highly successful, first modern small satellite project. He is also listed in Via Satellite's "Top 100 Executives in the Satellite Communications Industry". Dr. Stuart has published over 90 professional papers on the topics of small satellite systems, space technologies and communications satellite economics.

Teledesic