

THE TELEDESIC SATELLITE SYSTEM

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ABSTRACT

There is a significant worldwide demand for broadband communications capacity. Teledesic plans to meet this demand using a constellation of 924 low-Earth orbit (LEO) satellites operating in Ka-band (30/20 GHz). The Teledesic constellation incorporates over 100,000 active-element phased-array antennas. Subscriber terminals will account for an additional 20 million antennas. The Teledesic network will be one of the major consumers of Ka-band GaAs MMICs in the late 1990's. Economies of scale will result in a low per subscriber cost.

INTRODUCTION

The Teledesic Network uses a constellation of low-Earth orbit (LEO) Ka-band satellites to provide a variety of services including multimedia conferencing, video conferencing, videotelephony, distance learning, and voice. The satellite uplinks operate in the 30 GHz band and the downlinks operate in the 20 GHz band. The constellation consists of 924 satellites at 700 Km altitude in 21 orbital planes inclined at 98.2°. The orbital planes are spaced 9.5° apart.

The Teledesic Network provides low-cost worldwide untethered low-delay bandwidth-on-demand to geographically diverse users in addition to wideband trunking capability between a limited number of sites worldwide. A family of subscriber terminals provide on-demand data rates from 16 Kbps up to 2.048 Mbps (E1), and for special applications from 155.52 Mbps (OC-3) up to 1.24416 Gbps (OC-24). This allows a flexible, efficient match between system resources and subscriber requirements.

The Teledesic Network provides service quality comparable to today's modern terrestrial communication systems, including fiber-like delays, bit error rates less than 10^{-9} , and rain availability of 99.9% over most of the United States. The 16 Kbps basic channel rate supports low-delay voice coding that meets "network quality" standards.

The Teledesic constellation has a capacity equivalent to a peak load of more than 2,000,000 simultaneous full-duplex 16 Kbps connections, corresponding to over 20,000,000 subscribers at typical "wireline" business usage levels.

The system provides 24 hour seamless coverage to over 95% of the Earth's surface and almost 100% of the Earth's population.

SYSTEM DESIGN

The network (Figure 1) uses fast packet switching technology based on Asynchronous Transfer Mode (ATM) developments. Each satellite in the constellation is a node in the fast packet switch network, and has intersatellite communication links with eight neighboring satellites. This interconnection arrangement forms a non-hierarchical geodesic network that is tolerant to faults and local congestion.

The Teledesic Network uses an Earth-fixed cell design to minimize hand-offs. The Earth's surface is mapped into a fixed grid of approximately 20,000 "supercells". Each supercell is a square 160 Km on each side and is divided into 9 cells as shown in Figure 2.

Teledesic uses a combination of space, time, and frequency division multiple access. At any

instant of time each fixed supercell is served by one of 64 transmit and one of 64 receive beams on one of the Teledesic satellites. The scanning beam scans the 9 cells within the supercell with a 23.111 msec scan cycle. Each scanning beam supports 1440 16-Kbps channels. FDMA is used for the uplinks and asynchronous TDMA (ATDMA) for the downlinks.

The on-orbit configuration of the Teledesic satellite, Figure 3, resembles a flower with eight "petals" and a large boom-mounted square solar array. The deployed satellite is 12 m in diameter and the solar array is 12 m on each side. Each petal consists of three large panels containing the phase-array antennas. The octagonal baseplate also supports eight pairs of intersatellite link antennas, the two satellite bus structures that house the engineering subsystem components, and propulsion thrusters. A third satellite bus structure, containing power equipment and additional propulsion thrusters, is mounted at the end of the solar array boom. The solar array is articulated to point to the sun.

COMMUNICATIONS LINKS AND TERMINALS

All of the Teledesic communications links transport data and voice as fixed-length 512 bit packets. The links are encrypted to guard against eavesdropping. Terminals perform the encryption/decryption and conversion to and from the packet format.

The uplinks use dynamic power control of the RF transmitters so that the minimum amount of power is used to carry out the desired communication. Minimum transmit power is used for clear sky conditions; transmit power is increased to compensate for rain.

The Teledesic Network accommodates a wide variety of terminals and data rates. Standard Terminals include both fixed-site and transportable configurations that operate at multiples of the 16 Kbps basic channel payload rate up to 2.048 Mbps (the equivalent of 128 basic channels). These terminals use antennas with diameters from 16 cm to 1.8 m as determined by the terminal's maximum transmit channel rate, climatic region, and availability requirements. Their average transmit power varies from less than 0.01 W to 4.7 W

depending on antenna diameter, transmit channel rate, and climatic conditions. All data rates, up to the full 2.048 Mbps, can be supported with an average transmit power of 0.3 W by suitable choice of antenna size.

Within its service area each satellite can support a combination of terminals with a total throughput equivalent to over 100,000 simultaneous basic channels.

The Network also supports a smaller number of fixed-site GigaLink Terminals that operate at the OC-3 rate (155.52 Mbps) and multiples of that rate up to OC-24 (1.24416 Gbps). Antennas for these terminals range in size from 28 cm to 1.6 m as determined by the terminal's maximum channel rate, climatic region and availability requirements. Transmit power varies from 1 W to 49 W depending on antenna diameter, data rate, and climatic conditions. Antenna site-diversity can be used to reduce the probability of rain outage in situations where this is a problem.

GigaLink Terminals provide gateway connections to public networks and to Teledesic support and data base systems, as well as to privately owned networks and high-rate terminals. Each satellite can support up to sixteen GigaLink terminals within its service area.

Intersatellite Links (ISLs) operate in the 60 GHz band. They interconnect each satellite with its eight neighbor satellites. Each ISL operates at the OC-3 rate, and multiples of that rate up to OC-24 depending upon the instantaneous capacity requirement.

COMMUNICATIONS PAYLOAD

A functional block diagram of the communications payload is shown in Figure 4. The heart of the payload is the fast packet switch (FPS). It routes packets to and from the Scanning Beam (SB), GSL, and ISL transmitters and receivers. The FPS is essentially non-blocking with very low packet delay, and a throughput in excess of 5 Gbps.

The frequency reference subsystem provides stable frequency and time references to the SB, GSL, and ISL transmitters and receivers. The computer subsystem provides control

information to the FPS and the SB, GSL, and ISL transmitters and receivers.

The SB subsystem consists of 64 transmit channels and 64 independent receive channels plus spares. Each transmit channel accepts digital data packets from the FPS. The packets are encoded and modulated to form an IF signal. The IF signal is upconverted and applied to an active-element phased-array antenna incorporating GaAs MMIC power amplifiers. The antenna converts the RF signal to a free-space propagated waveform with the proper polarization for the Earth-fixed cell that it is serving. The signal frequency is pre-compensated to eliminate the apparent Doppler shift at the center of the Earth-fixed cell.

Each SB receive channel uses an active-element phased-array antenna incorporating GaAs MMIC low-noise amplifiers (LNAs) to convert free space propagated waveforms into a RF signal. The antenna selects the signal polarization corresponding to the Earth-fixed cell that it is serving. The RF signal is downconverted to an IF signal, demodulated, and decoded. The decoded data packets are sent to the FPS.

The SB antenna arrays are located on panels that are oriented at angles to the Earth's surface that reduce the beam steering requirements of each array to a few degrees. The antenna arrays on the inclined panels are elliptical in shape and produce elliptical patterns that compensate for the distortion from circular encountered at antenna grazing angles less than 90° with the Earth's surface.

The GSL subsystem consists of 16 transmit channels and 16 independent receive channels plus spares. Each transmit channel accepts digital data packets from the FPS. The packets are encoded and modulated to form an IF signal. The IF signal is upconverted and applied to an active-element phased-array antenna incorporating GaAs MMIC power amplifiers. The antenna converts the RF signal to a free-space propagated waveform with the proper polarization for the GigaLink Terminal it is serving. The signal frequency is pre-compensated to eliminate the apparent Doppler shift at the GigaLink Terminal.

Each GSL receive channel uses an active-element phased-array antenna incorporating

GaAs MMIC LNAs to convert free-space propagated waveforms into a RF signal. The phased-array antenna selects the signal polarization corresponding to the GigaLink Terminal it is serving. The RF signal is downconverted to an IF signal, demodulated, and decoded. The decoded data packets are sent to the FPS.

The ISL subsystem consists of eight transmit channels and eight independent receive channels plus spares. Each transmit channel accepts digital data packets from the FPS. The packets are encoded and modulated to form an IF signal. The IF signal is upconverted and applied to an active-element phased-array antenna incorporating GaAs MMIC power amplifiers. The antenna converts the RF signal to a free-space propagated waveform with the proper polarization for the satellite with which it is communicating. The signal frequency is pre-compensated to eliminate the apparent Doppler shift at the receiving satellite.

Each ISL receive channel uses an active-element phased-array antenna incorporating GaAs MMIC LNAs to convert free space propagated waveforms into a RF signal. The antenna selects the signal polarization corresponding to the satellite it is serving. The RF signal is downconverted to an IF signal, demodulated, and decoded. The decoded data packets are sent to the FPS.

ANTENNA REQUIREMENTS

The Teledesic Network phase-array antenna requirements are summarized in Table 1. The Standard Terminal and GigaLink Terminal antenna gains vary as a function of the maximum uplink channel rate, climatic region, and availability requirements.

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Table 1. Phase-Array Antenna Requirements

| Type | Frequency (GHz) | Gain (dBi) | Quantity |
|-------------------|-----------------|------------|-----------|
| Satellite SB REC | 30 | 30 | 64,000 |
| Satellite SB XTM | 20 | 30 | 64,000 |
| Satellite GSL REC | 30 | 41 | 16,000 |
| Satellite GSL XTM | 20 | 41 | 16,000 |
| Satellite ISL REC | 60 | 48 | 8,000 |
| Satellite ISL XTM | 60 | 48 | 8,000 |
| Standard Terminal | 30/20 | various | 2 million |
| GigaLink Terminal | 30/20 | various | 10,000 |

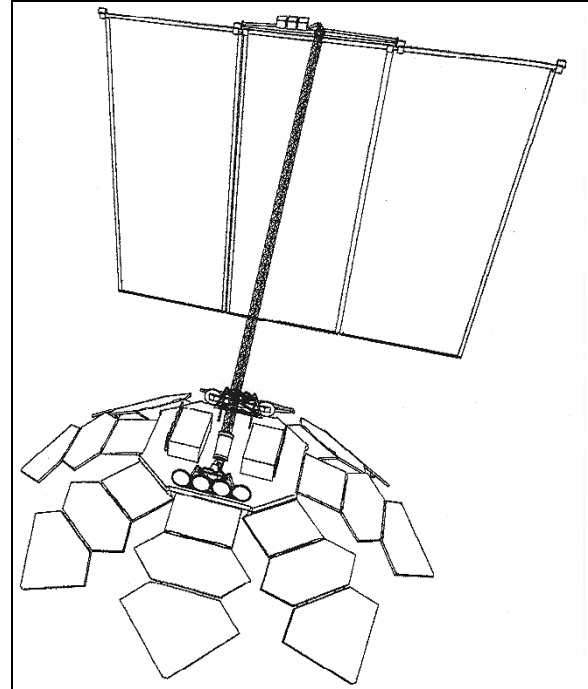


Figure 3 – Teledesic Satellite

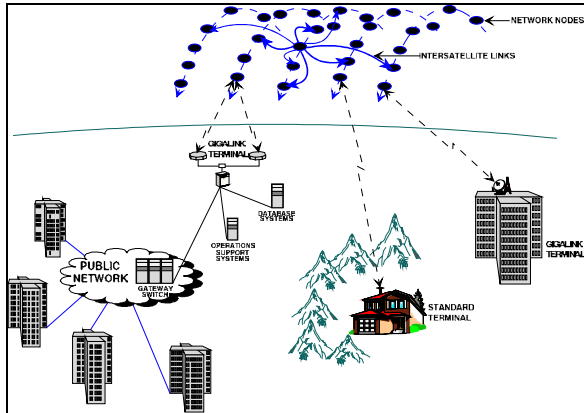


Figure 1 – The Teledesic Network

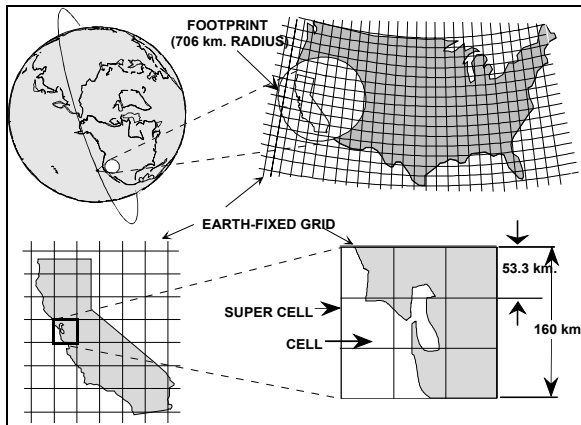


Figure 2 – Earth-Fixed Cells

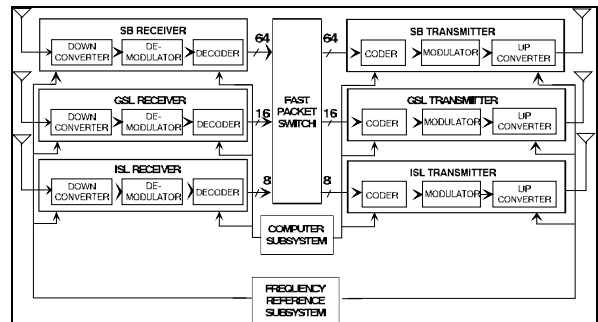


Figure 4 – Communications Payload Functional Block Diagram