



Odyssey Personal Communications Satellite System

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N 9 4 - 2 2 7 8 7



3rd International Mobile Satellite Conference and Exhibition

Abstract

The spectacular growth of cellular telephone networks has proved the demand for personal communications. Large regions of the world are too sparsely populated to be economically served by terrestrial cellular communications. Since satellites are well suited to this application, TRW filed with the FCC on May 31, 1991 for the Odyssey construction permit. Odyssey will provide high quality wireless communication services worldwide from satellites. These services will include: voice, data, paging, and messaging. Odyssey will be an economical approach to providing communications. A constellation of 12 satellites will be orbited in three, 55° inclined planes at an altitude of 10,354 km to provide continuous coverage of designated regions. Two satellites will be visible anywhere in the world at all times. This dual visibility leads to high line-of-sight elevation angles, minimizing obstructions by terrain, trees and buildings. Each satellite generates a multibeam antenna pattern that divides its coverage area into a set of contiguous cells. The communications system employs spread spectrum CDMA on both the uplinks and downlinks. This signaling method permits band sharing with other systems and applications. Signal processing is accomplished on the ground at the satellite's "Gateway" stations. The "bent pipe" transponders accommodates different regional standards, as well as signaling changes over time. The low power Odyssey handset will be cellular compatible. Multipath fade protection is provided in the handset.

New Opportunity for Mobile Comm

Terrestrial-based mobile (cellular) communications have grown explosively over the past decade. There are nearly ten million cellular telephones in service within the United States in 1992. The use of radio-telephones is just the first stage in a move to wireless personal communications. Because part of the population is widely disbursed, it cannot be economically served by terrestrial wireless systems. Satellites are more ideally suited to provide service to the population in more remote regions. This includes potential subscribers who cannot be served at all and terrestrial users who have temporarily moved into regions where no service is provided. A new generation of satellites can provide economical access to individuals without the need for heavy, costly satellite Earth terminals. Decisions at the 1992 WARC have opened the way for worldwide satellite based mobile communications using designated frequencies in the S and L Bands.

For nearly 30 years satellites have been used to provide communications to broad areas of the world. Nearly all these satellites have been maintained in geostationary orbit so that the ground antennas could point to a fixed location. User terminals were either fixed ground stations with large disk antennas or large portable ("lugable") terminals which required a disk type antenna with the capability to point at GEO satellites.

The logical extension of satellite services to personal communications is the use of hand-held telephones. Improvements in microcircuits over the past decade have made possible the packaging of an entire satellite earth station into a hand-held telephone, with an omnidirectional antenna. The satellites no longer need to provide the stationary ground track of the GEO satellite. There are several difficulties related to the 35,860 km GEO altitude and equatorial orbit. The orbit is located so far from the earth that 270 milliseconds is required for a signal to propagate to the satellite and return. This causes confusion and inefficiency with interactive communications like voice transmission. Many voice users find the GEO-delay annoying, even when echo cancelers are employed. This great distance also results in signal attenuation. At high latitudes, geostationary satellites are observed at low elevation angles due to the zero-degree inclination of the orbit. Subscribers may experience signal blockage by terrain, vegetation, or buildings.

The new microcircuitry permits consideration of orbits nearer the Earth, reducing path loss and propagation delay, simplifying satellite design and reducing space segment cost. Careful orbit design will keep the elevation angles to the satellites can be kept well above the horizon at all latitudes. The question is: Which orbit is best to take advantage of this frequencies designated by the 1992 WARC for personal mobile communications?

Satellite Altitude & Constellation Selection

Selection of the orbit is a trade-off among the following among the following factors: number of satellites & launch flexibility; system reliability; spacecraft antenna size; spacecraft power; cost of each satellite and life cycle cost; satellite lifetime; terrestrial view angles / line-of-sight elevation angle; degree of Earth coverage; effect of Van Allen belt radiation; handset power; and propagation delay

These factors are interrelated and can only be assessed by synthesizing a fully optimized design (see figure 1). A trade off between design cases for two low Earth

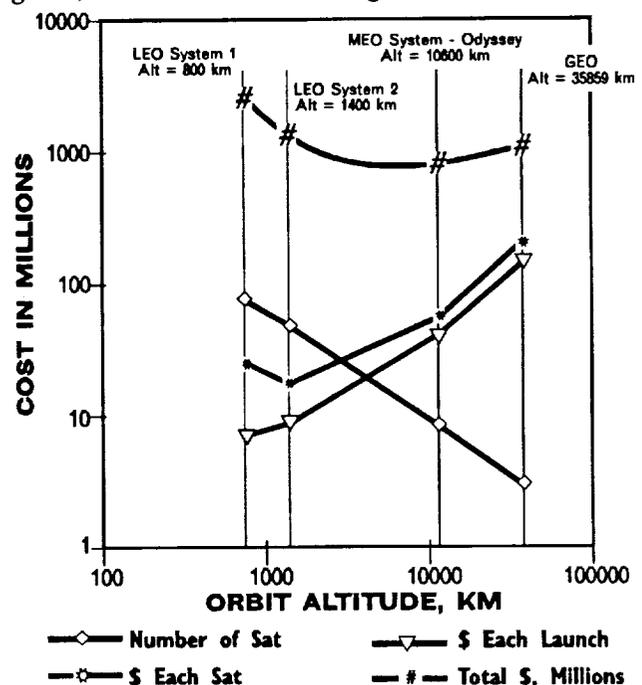


Figure 1: Satellite Cost Trades

orbits (LEO), Medium Earth Orbit (MEO), and GEO satellites was made. For each case the communications mission was to provide a comparable number of personal communications circuits to 0.5-Watt handsets. Each constellation was designed to provide continuous worldwide service with a terrestrial view angle of not less than 10 degrees. Each case was then assessed for total cost.

Geostationary satellite designs require only three or four satellites to provide service to the entire world, however require more than one hundred very narrow beams (produced by very large apertures), complex transponders, and large amounts of power to provide personal communications.

Since propagation losses drop with square of the distance, at lower altitudes satellite antennas can be smaller and transmission power can be reduced. Satellites can be smaller and less expensive in lower orbits since less power is required to close a communications link. The launching cost drops with altitude since the satellites are smaller and less energy is required. However the number of satellites increases rapidly as the orbit altitude drops as shown by the diagonal line in Figure 1. Very close to the Earth the slant range for transmission becomes the governing factor therefore the relative savings are mitigated by the need for a large number of satellites. For Low Earth Orbits nearly 70 satellites are required to provide continuous service. Close to the earth the satellite cost is dominated by slant range more than altitude.

The most significant feature of this trade is that the minimum total cost falls between geosynchronous and low earth orbit as shown by the curve at the top of this graph. The medium altitude orbit requires only twelve satellites to provide continuous global visibility.

Odyssey Orbit

The selected Odyssey constellation contains 12 satellites at an altitude of 10,354 km with four satellites in each of three orbit planes inclined at 55° (see figure 2). The indicated constellation provides continuous, global coverage with dual satellite visibility in some major regions. The Odyssey MEO provides several advantages beyond low

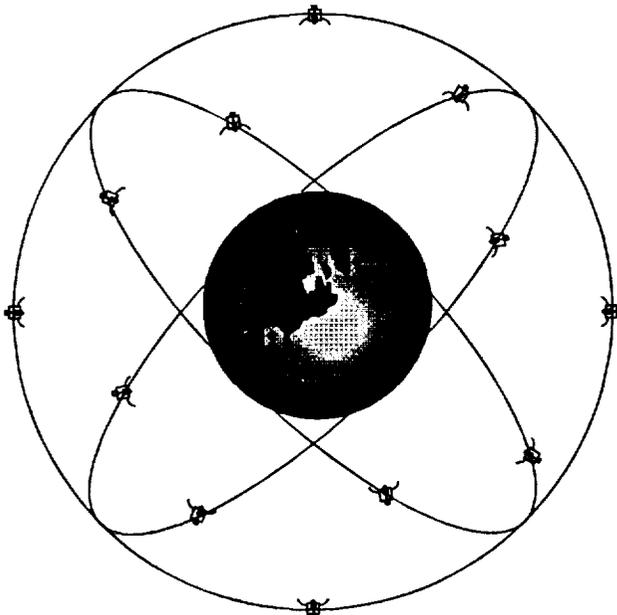


Figure 2: Odyssey Constellation

cost: the propagation time delay is reduced to only 68 to 83 milliseconds which is imperceptible in human conversations. The satellites in this constellation are designed for a 10 year on-orbit lifetime. LEO satellites have a typical lifetime of 5 to 7 years. Only nine satellites are required to ensure that one satellite is visible at all times. Consequently, continuous service to several regions can be started with only nine satellites. By adding only three satellites two or three satellites are visible at all times and service can be provided to most of the world's land mass. This relatively small constellation can be developed and launched in a short time. This will ensure that service can be provided in a short time to market.

Odyssey System Architecture

The Odyssey System is designed to fulfill the following requirements and criteria: minimum life cycle capital cost & low cost to end user; maximum time delay of 100 ms; minimum number of satellites; access to a low power handset; flexible **Worldwide** land mobile service; no satellite on-board processing; no satellite-to-satellite cross-links; frequency sharing by CDMA; reliable continuity of service; low risk of call dropout; clear, high quality voice circuits

The Odyssey system will provide economical, high quality, personal communication services from medium altitude orbit (MEO) satellites. Services include voice, data, and messaging/paging. Odyssey will provide a link between mobile subscribers and the public switched telephone network (PSTN) via dedicated ground stations (Figure 3). The satellite shall illuminate its assign region with a 19

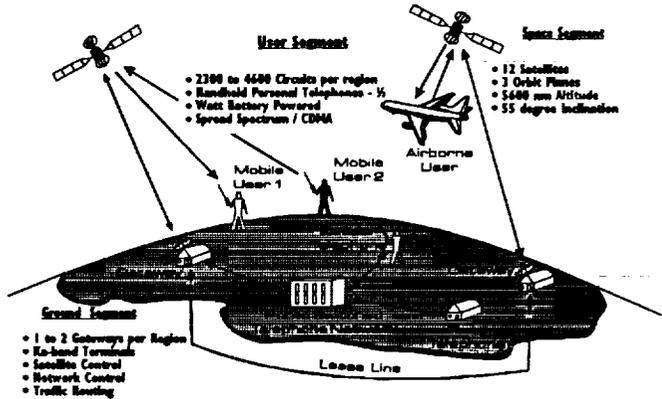


Figure 3: Odyssey System Overview

beam, 5-degree-beamwidth multibeam arrangement. A 37 beam arrangement is currently under study to improve the link margin to the user. Figure 4 shows this pattern covering CONUS. For intercontinental calls, the terrestrial toll network will be used.

Economical design is important so that the subscriber service charge can be priced in line with terrestrial service charges. Economy is achieved through low investment cost, a major consideration for all satellite programs because the production and launch of reliable satellite networks is a very expensive business. TRW achieves this with a small constellation of MEO satellites that provides continuous global coverage.

Call Setup with Odyssey

Priority is given to use of the terrestrial cellular services. When a call is placed the HPT first senses the presence or absence of cellular frequencies and attempts to

place a call through the local cellular network. If cellular service is not available or the call is blocked, then the call is routed through Odyssey. User circuits established through a particular satellite enter the PSTN at a ground station located within the region served by the satellite. Odyssey call setup is conducted via order wire to a master control station. A separate order wire channel is assigned to each satellite antenna beam. In making a circuit request, a user terminal transmits requests to overhead satellites. The user is assigned to the beam which provides the strongest signal to the base station, and is instructed to use a suitable power level and a particular spread spectrum code appropriate to that beam. The entire call setup procedure is transparent to the user.

In most cases, a user will remain within a given cell for the duration of a call, thus precluding the need for handover. There are two reasons for this. First, the cells are relatively large; the cell diameter is typically 800 km (497 mi). Second, the cell pattern will remain relatively fixed, since a satellite is continuously reoriented to maintain coverage of its assigned region. Consequently, the need to reassign frequency subbands and spread spectrum codes will occur quite infrequently. But capability will be provided to reassign a user to a different beam if necessary. In

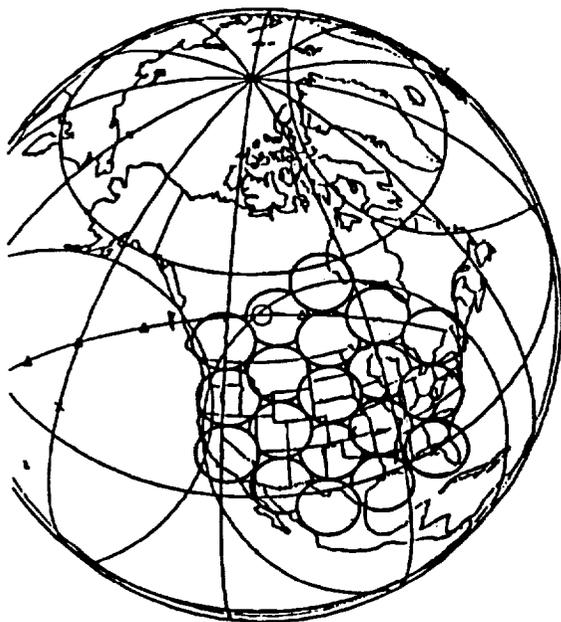


Figure 4: Odyssey Beam Pattern

the case of very long callers, circuit transfer to another satellite can be performed at the base station without the participation of the subscriber.

Satellite Lifetime

The "total cost of ownership" depends on all capital and operating expenditures over a fixed period. Cellular facilities are typically depreciated over a 7-year period, for example. Geostationary satellites are currently designed for lifetimes of ten to fourteen years. Experience has shown that the electronics designs and backup techniques support these durations. Lower altitude satellites, however, have experienced shorter lifetimes due to degradation by atmospheric deterioration such as exposure to ionized oxygen. Due to the "South Atlantic Anomaly", low altitude satellites

are also exposed to high levels of radiation from the Van Allen Belts. In some cases, less redundancy has been built into lower altitude satellites. Odyssey will be designed with full redundancy for 10 years on-orbit lifetime to reduce the cost of ownership.

Communications System Design Drivers

The Odyssey communication system design is driven by several key requirements of personal telephone users. Other driving requirements are manufacturability and reliability of the key system component from the user's point of view - the Handheld Personal Telephone (HPT). Cost effectiveness and capability to generate revenue are also drivers. These key requirements are:

- Full duplex voice communication
- High quality voice encoding: a mean average score (MOS) of 3.5 or better
- 24 hours communication system availability
- Communication capability covering all of the global land masses
- Low cost HPTs
- Dual mode compatibility with terrestrial cellular systems
- Battery capacity for 90 minute talk time duration
- Battery capacity for 24 hour standby mode
- HPT operation similar to terrestrial cellular
- Alphanumeric paging capability
- Meets health and safety standards
- Data transmission capability

Frequency Plan

Frequencies for satellite based personal mobile communications were designated at the 1992 WARC. Uplink transmissions from user to satellite are conducted at L-band (1610 to 1626.5 MHz), while downlink transmissions are at S-band (2483.5 to 2500 MHz). The Odyssey signaling method will be spread spectrum (CDMA), which has been proven in numerous government applications. Spread spectrum permits sharing of the frequency spectrum by multiple service operators. In contrast, FDMA or TDMA signaling requires extensive frequency coordination between multiple operators. Spread spectrum also reduces the data rates and power for signal transmission compared to TDMA.

Transmissions between the ground station(s) and the satellites take place at Ka-band. Distinct subbands are reserved for the transmissions to and from each cell. In the return direction, for example, the composite signals received from the different cells are frequency-division-multiplexed (FDM) prior to translation from L-band to Ka-band. Conversely, in the forward direction, the satellite demultiplexes the FDM uplink transmission into its component subband signals following translation from Ka-band to S-band. The composite subband signals are then routed to the various downlink antenna feeds. The required Ka-band bandwidth in either direction is the product of the subband bandwidth and the number of cells in the satellite antenna pattern.

Handheld Personal Telephone (HPT) Design

The major Odyssey HPT design driver is simplicity and low cost. A user will perceive no apparent difference between HPT usage in the Odyssey system and today's terrestrial cellular system HPTs. The Odyssey user terminal will be a modified version of a cellular HPT, which can operate at either cellular or satellite frequencies. Odyssey HPTs will use antennas of a quadrifilar helix design.

The Odyssey HPT will transmit approximately 0.5 Watt average power. This transmit power level will be adequate for both voice and digital data transmission. The transmit power level provides an appropriate margin against loss due to rain, vegetation, path distance, etc. It is important to point out that since the Odyssey system operates with high elevation angles of greater than 30 degree, less margin is required for path loss parameters than with LEO systems which must operate at shallow elevation angles.

Odyssey HPTs will be compatible with terrestrial cellular signal formats. This will be achieved by the addition of microelectronic chips to existing HPT designs to produce interoperability with both cellular and Odyssey. The chip sets will be matched to the standards of various regions of the world. In Europe, the HPTs will be interoperable with GSM. In the U.S., the HPTs will work with the American Digital Standard (ADS), Advanced Mobile Phone Service (AMPS), or Odyssey. The Odyssey HPT will meet all of the communication system design driver requirements listed in the previous section.

Gateway Stations

The Gateway station shall provide the connection between the Odyssey satellite link and the PSTNs in each region. Most calls will be directed to the local PSTN. Long distance calls will be directed to the designated long distance PSTN in the Gateways region. The rare Odyssey to Odyssey calls will be routed to the appropriated Odyssey Gateway station through dedicated inter-Gateway leased lines.

The gateway also provides all of the signal processing for the Odyssey system.

Each gateway station will be equipped with four 10-ft tracking antennas which are separated by 30 km. Three of the antennas may be simultaneously communicating with as many satellites.

The fourth antenna will be available to acquire an additional satellite, so that handover of responsibility from one satellite to another can take place without a gap in communications. The fourth antenna can also serve a diversity function in the event of heavy rainfall, since rain cells are typically much less than 30 km in diameter.

Payload Design

Odyssey incorporates a conventional 19 channel architecture for both the forward and return links. Redundancy paths are not shown. In the return link each of the 19 receive beams will be fed to low noise amplifiers (LNA), upconverted to Ka-band, amplified by a high power amplifier or TWTA, and then directed to the Ka-band base station antenna.

The forward link will be the complement of the return link. The Ka-band signal will be received from the base station antenna, down converted, filtered, amplified and directed to the S-band antenna. No feed networks are required for antenna beam shaping. Each transmit channel will be connected to a power amplifier hybrid network to

allow for maximum loading of beams in high traffic areas. A simplified block diagram of the transponder is shown in Figure 5.

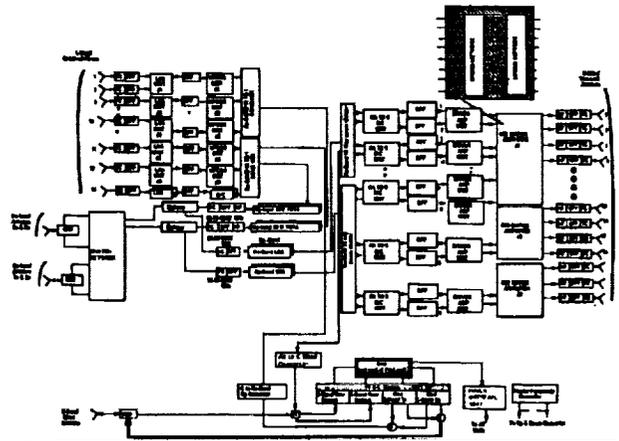


Figure 5: Odyssey Payload Block Diagram

All communication processing is performed on the ground, simplifying the design of the payload on the satellite. This "bent pipe" system also has the advantage of allowing different communication formats to be routed through the Odyssey satellite to accommodate various regional demands. The "bent pipe" design also gives the Odyssey system the capability of updating the communication formats with future developments in communication technology.

Spacecraft Design

The spacecraft platform will be derived from the TRW Advanced Bus development program (see figure 6). TRW has constructed a test bed to demonstrate the Advanced bus design. This new TRW Advanced Bus concept

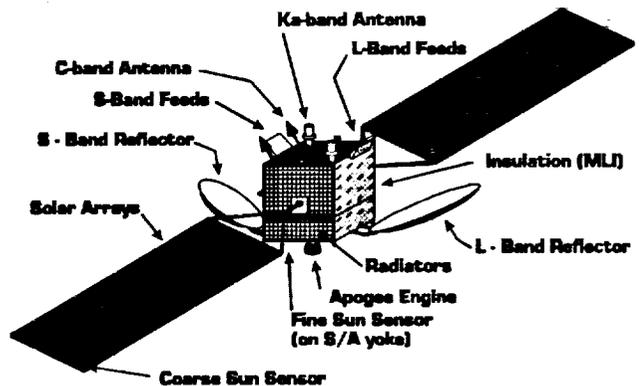


Figure 6: Odyssey Satellite

is successfully being used on several new satellite programs, including NASA's Total Ozone Mapping Satellite (TOMS). TRW is also drawing on its experience from building fleet spacecraft systems such as the U.S. Navy's FLTSATCOM (provides worldwide mobile fleet communications) and NASA's Tracking and Data Relay System (TDRS). Also TRW has been performing studies for NASA on upgrading the TDRS Satellites.

The L-band reflector is approximately 2.25 meters and the S-band reflector is 1.4 meters in diameter. Two Ka-band antennas are gimbal mounted on the Earth-facing panel. The spacecraft points the S and L-band antennas by body steering. Solar Arrays are kept pointed toward the sun

by use of single axis solar array drives. The satellites are launched two at a time on an Atlas II and Ariane 4.

The effects of the radiation environment have been analyzed for the Odyssey satellite. The Van Allen belts the major source of potentially damaging ionizing radiation. The selected Odyssey orbit puts the satellites between the outer and inner Van Allen Belts (Figure 7). Solar flares are another source of radiation. Flares are relatively more hazardous to geostationary satellites because the flares are deflected by the Earth's magnetic field. The Odyssey solar arrays, electronic components, and shielding have been

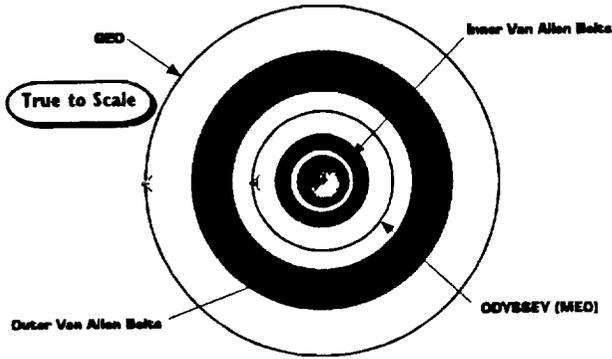


Figure 7: Orbit Position Relative to Van Allen Belts

selected and sized to tolerate the radiation environment for a 10 year mission. New TRW designs in solar arrays and electronic component assemblies has kept the weight of these components to a minimum.

Odyssey Constellation Landmass Coverage

Each satellite's multibeam antenna pattern divides its assigned coverage region into a set of contiguous cells. The total area visible to a satellite will have regions of significant population density, and regions with few subscribers. Consequently, the satellite antennas are designed to provide coverage to only a portion of the total area visible to the satellite. The antennas are fixed mounted to the satellite body. During the period that a satellite is assigned to a particular region, the satellite attitude is controlled so that the antennas remain pointed in the desired direction. Steering the antennas is a key feature of Odyssey which provides a unique benefit: telephone calls are never handed over from satellite to satellite and circuits are seldom passed from beam to beam. This avoids what can be a major communications synchronization problem for LEO satellites which frequently handover telephone calls from satellite to satellite.

Considerable study has been applied to the definition of the 9 service areas to cover the Earth (figure 8). At any time most of the satellites provide primary service to these regions. Additional satellites are used for the transi-

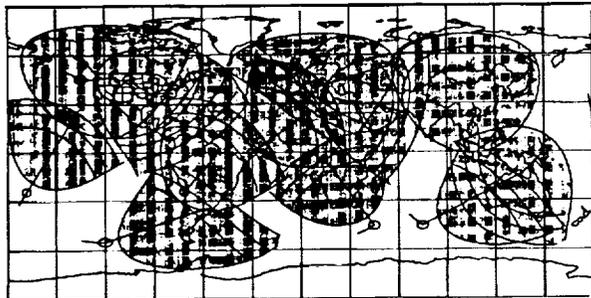


Figure 8: Odyssey Landmass coverage Areas

tion before a satellite moves on to the next assigned region. Traffic builds up on the approaching satellite while traffic wanes on the receding satellite. Cellular telephone calls typically last for only two to three minutes. Therefore, with coverage overlap of approximately 10 minutes, most calls will be completed before satellite coverage will be removed. Each satellite will be visible over any region for almost two hours, but will be only used during intervals that provide the highest elevation angles (typically 60 to 70 minutes). If responsibility for a region is shared among two or more satellites, multiple ground stations will be required. With the full constellation of 12 satellites, a minimum line-of-sight elevation angle of 30 degrees can be guaranteed to at least one of the satellites visible in every location more than 95% of the time. The satellite body steering of the S and L-band antennas provides considerable flexibility for defining service areas to match demand.

Capacity

The capacity of an individual satellite beam is governed by both thermal noise and "self noise" of the spread spectrum system. The capacity of each satellite is approximately 2300 voice circuits. Since the 12-satellite Odyssey constellation can provide dual satellite coverage of any region, the system capacity relative to a region like CONUS will be 4600 voice circuits.

With the basic constellation of 12 satellites, Odyssey will support 2.3 million subscribers worldwide. At least one voice circuit must be provided for each 100 subscribers to avoid call blockage during times of peak demand. Coverage could be expanded by increasing the number of satellites. Use of a synchronous waveform and orthogonal codes could further extend the number of voice channels. A combination of these methods could multiply the capacity by a factor of eight. These techniques could increase the theoretical Odyssey subscriber population to 18.4 million.

Elevation Angles

Perhaps the most important advantage of the Odyssey orbits is high view angles. Two Odyssey satellites will be visible anywhere in the world at all times. This dual coverage leads to high line-of-sight elevation angles, thereby minimizing obstructions by terrain, trees and buildings. Figure 9 shows the elevation angles for GEO, LEO, and Odyssey (MEO) satellites. Geostationary satellites provide

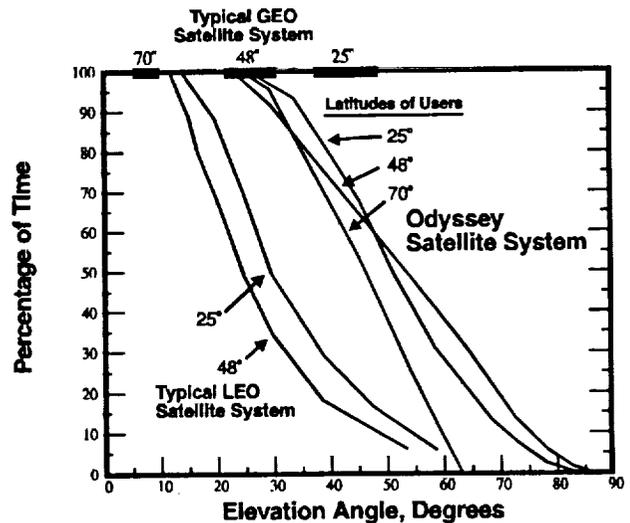


Figure 9: Percent of Time Highest Satellite is Greater than Elevation Angle

attractive view angles at latitudes near the equator, but very low view angles at high latitudes. This is illustrated at the top of Figure 9 for GEO. LEO satellites the influence of latitude and longitude is continuously varying since the satellites are moving relative to the Earth. Therefore LEO satellites would provide relatively low view angles most of the time as shown for the LEO system on the left side of Figure 9. But for the Medium Earth Orbit Odyssey the view angles average 45 to 55 degrees at all latitudes. With the full constellation, a minimum line-of-sight elevation angle of 30 (depending on user latitude) can be guaranteed to at least one satellite more than 95% of the time. This is a major benefit to the user since obstructions from trees, buildings and terrain can be avoided and less link margin is required in the communications link budget.

Demand for Mobile Comm Service

We also remember that communications is a service business. Provision of economical and quality service is essential. Service rates are an important factor which determines the success of any mobile satellite business. We get some insight into the economic elasticity of mobile communications service by looking at two segments: Cellular and INMARSAT. After 16 years INMARSAT has 18,000 subscribers paying an average rate of \$7.50 per minute. Cellular, after 8 years, has 17.6 million subscribers paying an average service rate of \$0.83 per minute. This suggests that decreasing prices by a factor of 10 increases demand by a factor of 1000. TRW has performed market surveys with 4300 participants. The data from this survey confirms the shape of this elasticity in the vicinity of the cellular prices. The survey also shows strong demand for a universal satellite based service. The Odyssey service cost is based on \$0.65 per minute and a subscriber base of one to two million subscribers. At higher service rates we would expect a sharp drop in the number of subscribers, which may not sufficiently support a business of this magnitude

Basic Market Areas

TRW has defined four segments which we are continuing to examine for the Odyssey service. We are also in the process of quantifying the demand for each group. These groups are:

- Corporate and government users who have a compelling need for continuous service over wide regions
- The second group is business travelers, both national and international roamers who lack service because of technical or "political" incompatibilities
- Residents of sparsely populated regions who will never receive cellular service because there are not enough subscribers to pay for the infrastructure
- Citizens of nations which lack communications infrastructure and would benefit from wireless communications.

Odyssey would provide high priority service for premium customers who require reliable mobile communications via a small HPT. Subscribers can have a single telephone which roves with them and doesn't require SIMM cards or special access codes. Odyssey provides the advantage over cellular of access at any location within the Odyssey service regions, almost anywhere in the world. Cellular wireless service is only available in metropolitan regions. Areas where the population is less than 40 to 50 people per square mile cannot be economically supported by Cellular systems. Many different standards prevent use of a cellular telephone outside of the country of origin. In many parts of the world even wire line service is not

available. Odyssey would provide communications service without concern for cellular incompatibility or lack of corresponding agreements. Odyssey is designed to provide high quality service. Odyssey employs large cells, up to 800 km (500 miles in diameter) over regions 4000 km across. Furthermore, calls are not switched or handed off to another satellite, minimizing the risk of call dropout. Odyssey requires virtually no handovers and subscribers will not experience processing delays or cease to function. Other systems may need to desynchronize frequently.

The best news for the subscriber is that the service rates would be competitive with cellular. From an communications operators perspective one of the strengths of the Odyssey system is the extraordinary flexibility for adjusting service regions. Odyssey can provide expanded capacity in areas where the demand is greatest.

Odyssey's Relationship With Telecoms

Odyssey will establish strategic service partnerships with several telephone companies in order to cooperate with operators in every country. Odyssey would be a natural extension of the existing infrastructure. Odyssey would provide access to many potential customers who are currently out of reach. Odyssey would expand the customer base and reduce total investment cost in many cases. The Odyssey business plan presumes that many telephone companies around the world would participate in the service, distribution, operations and investment. We anticipate that a private prospectus will be offered later this year.

Odyssey Schedule

The Odyssey program has been fashioned to be the "first to market" with personal communications by satellite. The pacing element is regulatory approvals from the FCC. All business arrangements will be contingent on the U.S. regulatory approval since the U.S. is potentially the largest market for mobile communications. The conventional Odyssey satellites are designed for a three year development time after FCC approval. The relatively small number of satellites would be dual launched in one year using two different launch vehicles for diversity.

Concluding Remarks

New frequency allocations for Mobile Satellite Service (MSS) were approved at WARC'92. Regulatory approval will open the way for a new era of universal personal communications by satellite. Economic viability of MSS, however, will depend on the most cost effective solutions to satellite architecture. The most notable benefits of Odyssey system will be:

- *Low life cycle capital cost: fewer, simpler, longer life satellites & fewer base stations*
- *Flexible, reconfigurable worldwide coverage*
- *Continuous, reliable, uninterrupted service: higher view angles, no cell-to-cell handover*
- *High quality voice transmission: digital spread spectrum with imperceptible delay*
- *Subscriber convenience: inexpensive, easy to use, cellular compatible handset*
- *Competitive service rates: spectrum sharing*
- *Low space segment risk: Straightforward bent pipe transponder with proven hardware*
- *Manageable satellite operations: fewer moving parts.*