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THE GLOBALSTAR MOBILE SATELLITE SYSTEM FOR WORLDWIDE PERSONAL COMMUNICATIONS

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1.0 INTRODUCTION

Loral Aerospace Corporation along with Qualcomm Inc. have developed a satellite system which offers global mobile voice and data services to and from handheld and mobile user terminals with omnidirectional antennas. By combining the use of low-earth orbit (LEO) satellites with existing terrestrial communications systems and innovative, highly efficient spread spectrum techniques, the Globalstar system provides users with low-cost, reliable communications throughout the world. The Globalstar space segment consists of a constellation of 48 LEO satellites in circular orbits with 750 NM (1389 km) altitude. Figure 1 shows the global coverage. Each satellite communicates with the mobile users via the satellite-user links and with gateway stations.

The gateway stations handle the interface between the Globalstar network and the PSTN/PLMN systems. Globalstar transceivers are similar to currently proposed digital cellular telephones in size and have a serial number that will allow the end user to make and receive calls from or to that device anywhere in the world.

The Globalstar system is designed to operate as a complement to existing local, long-distance, public, private and specialized telecommunications networks. Service is primarily designed to serve the rural and thin route communications needs of consumers, government users, and private networks.

Due to the orbit selection and the use of CDMA spread spectrum technology the number of circuits over a region is increased due to multiple satellite coverage. Each satellite operates as a repeater in space, eliminating complex call setup procedures and on-board processing. Globalstar has been configured to link the mobile user to a terrestrial gateway through a single satellite so that the system requires no satellite crosslinks.

Globalstar offers services which are not currently available, such as world wide cellular roaming. Globalstar service offerings will meet the needs of the general public both domestically and globally where it is not cost effective to provide terrestrial based cellular services.

Signal availability and quality to the user is the most important factor in choosing a technology for MSS services. The user signal availability is determined by a large

number of factors which are statistically developed to determine what the user experiences during a MSS call. For example, a user which is stationary in a clear area will experience a certain propagation effect while another user using a hand held device while in a vehicle traveling under a heavily leafed tree canopy may experience a different value. The Globalstar user receive signal level and transmit power is adjusted to account for impairments. Rural and suburban propagation models have been developed by Vogel of the University of Texas [1] which show the probability of needing margin in certain conditions. These models when combined with multiple satellite availability (path diversity) and elevation angle statistics from the satellite constellation determine signal availability.

2.0 CDMA IS OPTIMUM FOR THIS SERVICE

Frequency Division Spread Spectrum CDMA (FD/SS/CDMA) provides optimum and flexible service quality to the end user. The FD/SS/CDMA modulation choice allows multiple signal paths from more than one satellite which mitigates fading and blocking.

The user is provided signals which are optimized for the subscriber's environment. Link margin is provided to each user independently as the gateway senses that it needs margin. User margin is provided in three independent ways. First, there is thermal margin built into each link to account for the inherent thermal noise from all sources. Second, a power control ability is built into the hardware which when activated boosts the power amplifier output by up to 10 dB in 0.5 dB steps both under the direction of sensing circuits in the user equipment and under control of the gateway that is handling the call. This provides a total "link by link margin"

of 11 dB. Third, the Globalstar system constellation provides additional mitigation of shadowing and blocking using path diversity. This path diversity is equivalent to having more margin on a link by link basis. When these margins are used with the suburban/rural model for fading, shadowing and blocking, the resulting availability is shown in Figure 2. The results show that significant improvement in availability is provided with path diversity.

For example, the user equipment in a rural/suburban environment which is experiencing a fade will first sense a degradation of the receive frame error rate. The unit will open loop increase its power to maintain quality and send a request to the gateway which increases the forward link power. On the return link the gateway measures the frame error rate and E_b/N_0 and sends up/down power control commands to the user unit closed loop. At the same time the uplink signals are being received by a second or third satellite, since the Globalstar system provides multiple satellites in view of the user's omni-directional antenna. The signal level of these alternate paths is measured by the same gateway serving the user. The gateway software controls both the power sent to and transmitted by the user as well as the usage of the alternate signal paths. At a predetermined point, depending on the system loading, the alternate signal paths are combined by the gateway receivers improving the received signal from the user. The alternate paths are monitored for level and stability and according to preset thresholds the user is commanded to the best alternate path.

Link performance is assured by power control which maintains the service quality constant over a wide range of fading, shadowing and blocking environments. For satellite systems fading is Rician in nature and not typified by the Rayleigh

model. Globalstar link budgets provide adequate margins for Rician fading conditions while shadowing and blocking is provided by satellite diversity.

Users in severely degraded situations will obtain service in excess of that available from FDMA/TDMA systems. For example, a user may be in a situation where the power control and thermal margin of 11 dB has been exhausted and the user is in need of even more margin. Globalstar's system will sense this situation and the user transferred to another satellite which has a less degraded path.

With CDMA there is no "brick wall" in capacity or signal quality. The system operator has control of the user signals which are requesting services. The Globalstar system has been designed to provide maximum capacity under modeled conditions which represent average conditions expected for the market served. When circuit demand begins to peak the system control facilities adjusts the power distribution to maintain overall signal quality, individual signal links continue to power control as discussed above. When the system reaches maximum capacity at a certain quality, several options are available to the system operator. As examples, two of these options are discussed here. Unlike FDMA or TDMA systems where the capacity reaches the "brick wall" and no further users may be added to the system, the CDMA systems utilize graceful degradation to maintain flexibility. The operator may allow more subscribers to occupy the bandwidth, slightly degrading the overall signal quality from a Mean Opinion Score of 3.5 to 3 or less. Alternatively, the system operator can redistribute a portion or all of the users over more of the satellites in view, thus reducing the blocking and shadowing path diversity for the users which may need it. During these traffic peaking conditions some users may experience

some higher levels of noisy transmission and loss of signal quality for short periods of time.

The Globalstar system offers the system operator maximum flexibility in channel assignment. Since all frequencies are reused in all of the beams, the interaction between gateways is minimized. Since the frequency reuse factor is maximized and the traffic load is averaged over several satellites, the utilization of the satellite is maximized and system loading as discussed above can exceed 100%. The system, in addition, has excess circuits available for handoff and path diversity situations. By comparison, in FDMA and TDMA the frequencies must be assigned in blocks to certain beams and since there cannot be 100% frequency reuse, system efficiency is therefore reduced. Since the system efficiency is 100%, the maximum capacity to a region may be realized and the capacity to each country can be maximized.

With CDMA the ability to concentrate circuits in a small region is important for emergency and disaster communications. For these conditions only CDMA has the flexibility to allow maximum capacity in a small region. Combinations of demand assignment, decreased quality, and other CDMA techniques, can make thousands of circuits available compared to the "brick wall" limitation of FDMA/TDMA.

The spectrum utilization with CDMA systems is maximized. Multiple systems can share the bandwidth with few coordination factors. International sharing with other CDMA operators requires similar sharing coordinating. Since the system downlink Power Flux Density (PFD) around the world is limited and since operation of uplinks are limited by EIRP density and health hazard reasons, these parameters can be coordinated within reasonably small limits.

Considering the downlink sharing, the capacity of the spectrum is the addition of all systems operating with CDMA, less the inter-system interference. Essentially, this means that there are many more power sources (satellites) in view of the region that is being served. The degradation to each system is a percentage of its capacity due to sharing of the interference power between the systems. However, the coordinated result is greater than any single system alone. The usage of the spectrum by several CDMA systems is over twice that of a TDMA system.

The advantage of CDMA to various administrations around the world is the freedom from spectrum segmentation required for operation of a FDMA or TDMA system. Spectrum segmentation, if implemented, results in warehousing of spectrum. This means that if country A and country B are attempting to coordinate systems and one of these is an FDMA or TDMA system and the beams cover both countries, either all or in part, the portion segmented for the FDMA or TDMA system is unusable for the second country even if the first country doesn't bring its system into use. CDMA on the other hand prevents this warehousing. The full bandwidth is available to both countries. If one doesn't deploy, the other just experiences less interference in its system.

3.0 SYSTEM DESIGN FOR GLOBALSTAR OPTIMIZES THE USE OF CDMA

The advantage of Globalstar is that it uses simple and reliable satellites. Forty eight satellites are launched to provide maximum path diversity in the temperate zones and to handle peak traffic. If there are random failures of several satellites, the coverage of the system is not affected most of the time. Therefore, there is no

need to have hot spare satellites on orbit, nor the need to launch individual replacement satellites on a crash schedule. FDMA and TDMA systems, since they must only have single satellite coverage of a user, must replace their failed satellites as they fail.

Globalstar has high elevation angles in the temperate zones of the world, for example the average elevation angle in CONUS is up to 55 degrees. The minimum elevation angle, occurring only infrequently and for a very short duration of time is 20 to 32 degrees depending on location. These high elevation angles and path diversity mitigate shadowing and blocking. Reliable path diversity is provided by 100% two satellite coverage in CONUS, three satellite coverage up to 90% of the time and four-satellite coverage up to 35% of the time.

Globalstar has the lowest path delay of any of the proposed LEO systems with the maximum path delay, including vocoder processing, of less than 100 ms. The maximum propagation path delay is 18 ms for the user-satellite-gateway link; the remainder is processing. Since there is no onboard processing or inter-satellite links, the processing is minimized and the overall path delay is reduced, providing excellent quality without the need for echo cancelers, etc.

The implementation method chosen by LQSS allows an easy extension of terrestrial cellular developments underway. Qualcomm Incorporated has developed a CDMA cellular telephone system which improves the spectrum efficiency over analog by a factor of about 15. This system is being deployed currently in several wireline cellular systems in the USA. LQSS plans to modify this system slightly, to account for increased path delay and effects of doppler, and utilize it for satellite delivered cellular telephony.

As such, this is the only LEO system proposed which has a heritage for its gateway and user equipment.

A key element in Qualcomm's terrestrial system implementation is the use of a Rake receiver which makes use of all available signal paths to insure that a quality signal is delivered to the user and the gateway. A Rake receiver makes use of the CDMA modulation to receive many signal paths simultaneously and coherently combine them to develop the highest signal input to the decoder. A multiple finger receiver is operated, with each receiver assigned to a particular signal path to decode. A separate receiver continuously searches for signal paths with the user's code. Once a path is found it is assigned to a receiver finger. Logic within the receiver reviews the signal levels emerging from these receivers and performs decisions on combining. It is unimportant whether these are direct paths or multipath signals, all signals received are available to be combined.

The benefits of the usage of two satellite coverage and the Qualcomm unique RAKE receiver design, combined with mitigation of fading and blocking of the hand held user equipment, are very important. Consider the case of a user which is shadowed by a propagation impairment. At the onset of shadowing the user would normally be utilizing a single satellite path to a gateway. The second and third satellite paths, although present would not be in use. As the shadowing increases the unit senses an increased frame error rate, makes an open loop power increase and requests power control, the gateway responds and begins closed loop control. The signal level remains constant at the shadowed satellite. The increased power level will be transmitted by the second and third satellites to the gateway and, depending on system operation be utilized (closed-

loop) to optimize the user's power requirements. The need for excessive link margin is thus avoided.

4.0 SUMMARY

Globalstar will use a constellation of 48 satellites to provide continuous coverage of the areas of the world requiring mobile connectivity. The Globalstar system is designed to operate as a complement to existing local, long-distance, public, private and specialized telecommunications networks. Service is primarily designed to serve the rural and thin route communications needs of consumers, government users, and private networks. Frequency Division Spread Spectrum CDMA (FD/SS/CDMA) provides optimum and flexible service quality to the end user allowing multiple signal paths from more than one satellite which mitigates fading and blocking. Link margin is provided to each user independently as the gateway senses that it needs margin. Path diversity, guaranteed by multiple satellite coverage is equivalent to having more margin on a link by link basis. When these margins are used for mitigating fading, shadowing and blocking, the resulting availability is better than a TDMA system with higher margin but with no path diversity.

The Globalstar system offers the system operator maximum flexibility without the need for difficult synchronization, thereby allowing many gateways. Since CDMA maximizes frequency reuse, the traffic load is averaged over several satellites, the utilization of the satellite is maximized and system loading can exceed 100%. The spectrum utilization with CDMA systems is maximized. Multiple systems can share the bandwidth with few coordinating factors. International sharing with other CDMA operators requires similar sharing coordination. The advantage of CDMA to

various administrations around the world is the freedom from spectrum segmentation required for operation of a FDMA or TDMA system which reduces operational efficiency.

Reference [1]

NASA Reference Publication 1274, February 1992; Propagation Effects for Land Mobile Satellite System; Overview of Experimental and Modeling Results, Julius Goldhirsh and Wolfhard J. Vogel