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A Second Anniversary Operational Review of the OmniTRACS® - The First Two-way Mobile Ku-band Satellite Communications System

Irwin M. Jacobs, Allen Salmasi,
Klein S. Gilhousen, Lindsay A. Weaver, Jr.,
Thomas J. Bernard

QUALCOMM, Incorporated
10555 Sorrento Valley Road
San Diego, CA 92121
United States
Phone: (619) 587-1121
Fax: (619) 452-9096

ABSTRACT

A novel two-way mobile satellite communications and vehicle position reporting system currently operational in the United States and Europe is described. The system characteristics and service operations are described in detail and, technical descriptions of the equipment and signal processing techniques are provided.

INTRODUCTION

Within the past two years, a unique two-way mobile satellite communications and position location/reporting system, called the Omni–TRACS® system, has been introduced in the United States and Europe. This system, operates on a secondary basis in the 12/14 GHz Band, (Ku-band), which has been allocated to the Fixed Satellite Services (FSS) on a primary basis. Developed by QUALCOMM, Inc., the system is the first operational domestic mobile Ku-band satellite service to provide two-way messaging and position reporting services to mobile users throughout the United States. Blanket authority ("license") to construct and operate a Ku-band network of mobile and transportable earth stations and a Hub earth station was granted from the United States Federal Communications Commission (the "FCC") in February of 1989 for an application filed in December of 1987 [1]. Using a pair of Ku-band transponders on a domestic FSS satellite as described below, the system is capable of serving a population of user terminals ranging between 40,000-80,000 users depending on the average length of the messages being transmitted and the frequency of transmissions. As demand for the system grows additional Ku-band transponders can be leased from the satellite operator(s) and modularly added to the system to increase the overall capacity of the system.

The system began operational tests in January, 1988 when a mobile terminal was driven from the west coast to the east coast of the United States and back in constant communication with a Hub facility. Fully operational system providing for commercial services began in June, 1989. Terminals have since been installed in vehicles ranging from 18-wheel tractor-trailers to mini-vans, marine vessels and automobiles to bicycles. Operation has been very successful in all kinds of environments from wide open Western freeways to the concrete canyons of New York City.

As of June, 1990, in the U.S., over 9,000 mobile terminals are in operation using a pair of existing Ku-band transponders aboard GTE Spacenet Corporation's GSTAR-I satellite with another backlog of approximately 6000 mobile terminals scheduled for shipments. A European version of the OmniTRACS system, Eutel-TRACS®, is currently operational in Europe using Ku-band transponders aboard two EUTELSAT satellites. Typical users include those involved in public safety, transportation, public utilities, resource extraction, construction, agriculture, national maintenance organizations, private fleets, and others who have a need to send and receive information to vehicles, marine vessels or aircraft enroute. As vehicles travel across the U.S., they move out of range of

conventional land-based communication systems. This satellite-based system eliminates the range problems inherent with land-based systems in the U.S., creating a true nationwide network enabling users to manage mobile resources efficiently and economically.

SYSTEM AND SERVICE DESCRIPTION

Figure 1 shows the end-to-end system overview. The Ku-band mobile satellite communications network has three major components:

1. A Network Management Facility (NMF) for controlling and monitoring the network.

2. Two Ku-band transponders, aboard a U.S. domestic satellite located at 103 degrees West Longitude.

3. Two-way data-communication and position-reporting mobile and transportable terminals.All message traffic passes through the NMF. The NMF contains a 7.6 meter earth station including modems (the "Hub") for communication with the mobile terminals via the satellite, a Network Management Center (NMC) for network monitoring and control as well as message formatting, processing, management and billing, and land-line modems for connection with Customer Communications Centers (CCCs)[1]-[4]. The OmniTRACS NMC supports two-way data messaging, position reporting, fleet broadcasting, call accounting and message confirmation, and a host of other services.

System description

The system, as used in the U.S., uses two transponders in a single Ku-band Satellite. One transponder is used for a moderate rate of 5-15 kb/s continuous data stream from the Hub to all the mobile terminals in the system. The system users can also use the terminals in a transportable or fixed mode. Messages are addressed to individual mobile terminals or to groups of mobile terminals on this channel. The antenna utilized for the mobile terminal is vertically polarized on both receive and transmit. This necessitates the use of two transponders, one horizontally polarized and the other vertically polarized, for the mobile service. To provide for the secondary status of the return link transmissions (mobile terminal to the Hub) a combination of frequency hopping and direct sequence spread spectrum waveforms are utilized, together with low power, low data rate transmissions.

For the forward link, the system uses a triangular FM dispersal waveform similar to that used by satellite video carriers, resulting in interference properties similar to television signals but with substantially less energy outside of a 2 MHz bandwidth.

A second transponder on the same satellite is used by the return link. Each mobile terminal has a low transmit power level (+19 dBW EIRP). This power level allows data rates on the return link ranging from 55 to 165 b/s, which is dynamically adjusted depending on available link margin for each individual return link trans-
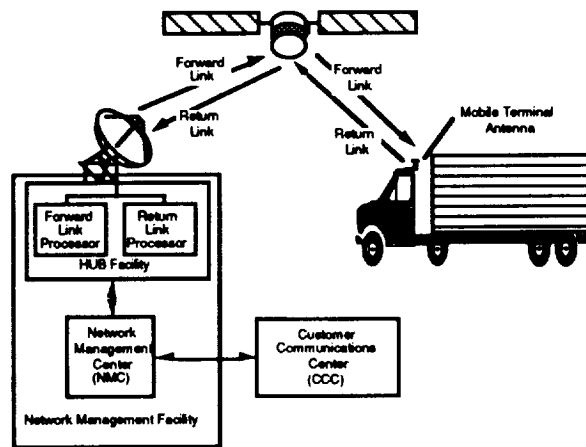

Fig. 1. Ku-Band Mobile Satellite Communications System Block Diagram

mission from the terminal. The antenna pattern of the mobile terminal is rather broad and, therefore, to mitigate for any potential for interference on the return link, several techniques are used:

1. Direct-sequence spread-spectrum techniques are used to spread the instantaneous power spectral density of each mobile uplink over a bandwidth of 1.0 MHz.

2. Frequency hopping and FDM techniques are used to ensure that the power spectral density produced by the combination of all active mobile terminals is uniformly spread over a bandwidth of up to 54 MHz, which can be adjusted to a narrower or wider bandwidth to optimize the return link throughput capacity.

3. The transmissions of the mobile terminals are very carefully controlled. A mobile terminal will not transmit unless commanded to do so, either as a direct request (acknowledgement, report, etc.) or as a response to a carefully defined—and limited—group poll. This polling technique controls the number and frequency location of mobile transmitters at all times so that the level of interference can be tightly regulated. Furthermore, reception of the command through the forward link at appropriate signal levels implies that the antenna is correctly oriented for transmission.

4. Back-up satellite frequency plans and bandwidth can be downloaded "over the air" to the mobile terminal providing for automatic switch-over to back-up transponders and/or satellites.

As a result of the above techniques, a network consisting of tens of thousands of mobile terminals causes no unacceptable interference to adjacent satellites. Initially for U.S. operations, LORAN-C derived position information in the mobile terminal was made available to the dispatcher or driver on a scheduled basis or on-demand. Alternatively, and for operations in other parts of the world, radio-determination providing for radio-location and radio-navigation satellite services may be provided either through the use of the Global Positioning System (GPS) or by direct range measurements through two or more Ku-band satellites depending on the cost of GPS receivers and availability/coverage provided by GPS as well as other Ku-band satellites. In April, 1990, QUALCOMM introduced the first provision of vehicle position location through the use of two Ku-band satellites and direct range measurements, the QASPR® system, while eliminating LORAN-C receiver circuit card from the mobile terminal, to obtain navigation accuracy of less than 1000 feet throughout the continental United States and without the error conditions prevalent in the existing LORAN-C system due atmospheric interference and the lack of radio signal coverage. The QASPR system uses the OmniTRACS TDMA timing signal formats in the forward and return link directions plus an auxiliary, low power forward link signal through a second Ku-band satellite (Ranger) to derive distance values. The distance values are then converted into the mobile terminal's latitude and longitude in real time as messages or acknowledgments are received at the NMC.

THE MOBILE SATELLITE TERMINAL

Figure 2 shows a functional block diagram of the mobile terminal. A microprocessor implements all of the signal processing, acquisition and demodulation functions. The antenna has an asymmetric pattern optimized for operations in the U.S. (approximately 40° 3 dB beamwidth in elevation and approximately 6° beamwidth in azimuth). It is steerable in azimuth only. A low-noise amplifier and conventional down-conversion chain provide a signal to the microprocessor for acquisition, tracking and demodulation. During transmission, an up-conversion and spreading chain provide a signal in the 14-14.5 GHz band to the 1.0 Watt power amplifier. This signal is transmitted via the steerable antenna that has a maximum gain of +19 dBi for a total transmit power of +19 dBW.

Whenever the mobile unit is not in receive synchronization, it executes a receive acquisition algorithm until data from the satellite can be demodulated. At this point, the antenna is pointed towards the satellite and messages can be received from the Hub. When commanded by the Hub, the mobile may start transmission of a message. The terminal is half-duplex, and transmissions are done at a 50% duty cycle to allow for continued antenna tracking of the received downlink signal. If at any time during a transmission the receive signal is lost, the terminal
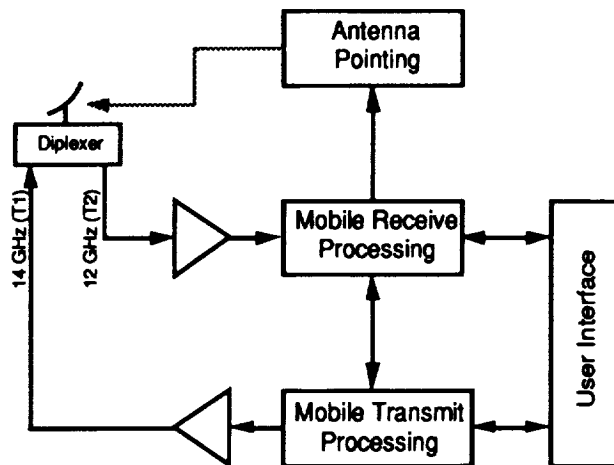
Fig. 2. Mobile Terminal Block Diagram

ceases transmission to prevent interference from being generated.

Description of return link

At the lowest return-link data rate, binary data at 55.1 bits per second is rate 1/3 convolutionally encoded to produce code symbols at a rate of 165.4 symbols per second. These code symbols are used five at a time to drive a 32-ary FSK modulator at a rate of 33.1 FSK baud. A 50% transmit duty cycle produces an FSK symbol period of 15.1 msec. The tones out of the FSK modulator are direct-sequence spread at a rate of 1.0 Megachip per second for an instantaneous bandwidth of 1.0 MHz. This 1.0 MHz bandwidth signal is then frequency hopped over up to a 54 MHz bandwidth. To maximize system capacity in areas with good satellite G/T, a 3.0x data rate of 165.4 b/s is also provided. This is implemented by a three times FSK symbol rate.

Return link power density

Figure 3 shows the mobile terminal main lobe antenna pattern in azimuth keeping elevation at maximum gain. This figure assumes a nominal boresight gain of 19 dBi. The sidelobes of this antenna are asymmetric and non-uniform, but stay below -12.0 dB relative to boresight gain. Table 1 shows the maximum transmit power density link budget for the return link with 250 units transmitting simultaneously. Table 1 combined with the transmit antenna pattern of Figure 3 produces the EIRP power density shown in

Figure 4. Also shown in Figure 4 is the U.S. Ku-band guideline for inbound transmissions out of VSATs, which indicates that the aggregate EIRP (measured in dBW/4 KHz) generated by 250 mobile units transmitting simultaneously is below the U.S. inbound transmission guideline for one VSAT.

Description of forward link

Binary data at variable rates of 4960.3 to 14,880.90 bits per second is rate 1/2 block encoded to produce code symbols at rates of 9,920.6 to 29,761.8 symbols per second, respectively. These code symbols are used to drive a BPSK modulator at rates of 9,920.6 to 29,761.8 PSK symbols, respectively. A triangle wave FM dispersal waveform is then applied, resulting in similar co-ordination properties to video signals for coordinating with adjacent satellite transponders or cross-polarized co-channel transponder on the same satellite. The power density calculations are shown in Table 2.

Coordination for the forward link waveform is easier than coordination of a video signal. The frequency band in the range of ±1.0 MHz about the center of the dispersal waveform will contain relatively high instantaneous power densities, but the frequency bands outside of this ±1.0 MHz range will drop off rapidly—even faster than video signals. Figure 5 shows the suggested coordination mask for the forward link signal compared with the coordination mask suggested for video signals.
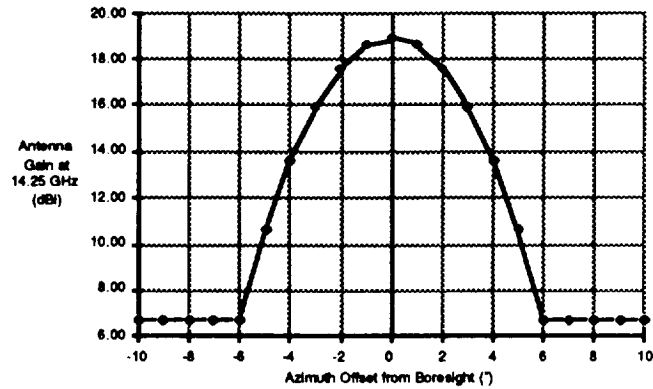
Fig. 3. Mobile Terminal Transmit Antenna Gain (Azimuth Cut)

Table 1. System Return Link Power Density

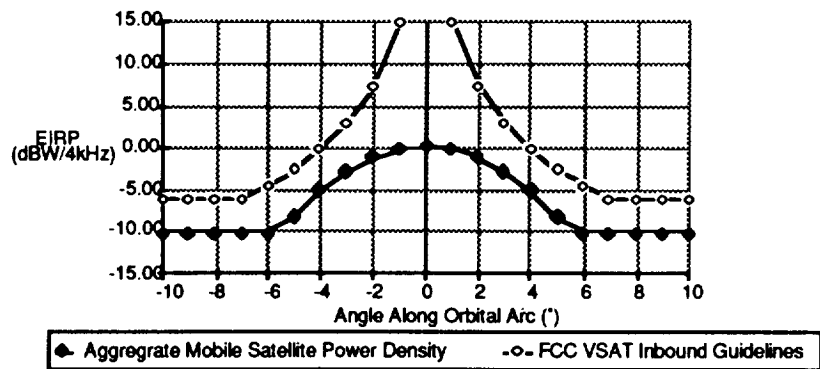| Max. Tx Power	1.26 Watt	1.0 dBw
Max. Tx Antenna Gain		19.0 dBi
Occupied BW	48,000,000 Hz	-76.8 dB/Hz
FCC Reference BW	4,000 Hz	36.0 dB-Hz/4kHz
Number of Uplinks	250	24.0 dB
Tx Duty Cycle	50%	-3.0 dB
System EIRP Density		0.2 dBW/4kHz

● Aggregrate Mobile Satellite Power Density   -○- FCC VSAT Inbound Guidelines

Fig. 4. Return Link Power Density Compared to the U.S. VSAT Inbound Power Density Limits

Table 2. Forward Link Power Density

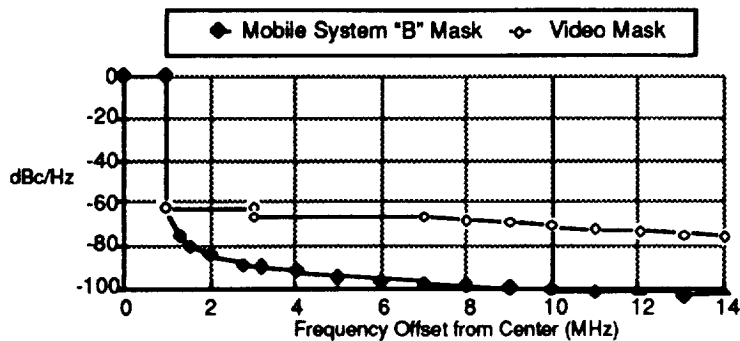| Satellite Transmit EIRP		44.0 dBW
Occupied Bandwidth	2,000,000 Hz	-63.0 dB/Hz
Reference FCC Bandwidth	4,000 Hz	36.0 dB-Hz/4kHz
Transmit Power Density		17.0 dBW/4kHz

Fig. 5. Suggested Coordination Mask for the System Forward Link vs. Video Coordination Mask

SYSTEM ENHANCEMENTS

Since initial implementation of the system, the need for a number of enhancements has been recognized and the following have been implemented:

a. TrailerTRACS™—a nominal hardware addition which provides for automatic identification and position reporting whenever a trailer is attached or dropped from a power unit (e.g., tractor) equipped with the system.

b. Driver Pager—a local paging unit which is operated by the system and which notifies the driver (up to 1000 yards from the vehicle) when an important message is waiting for him in the truck—can also be used as an alarm for "wake-up".

c. Message Return Receipt—provides the ability to have the system notify central operations or dispatch whenever a message has actually been read--analagous to certified mail with a return receipt.

d. Panic Button—provides the ability for a driver to hit one key or button, thereby initiating a "panic" message which is intercepted by the Network Management Center, causing a telephone call to be initiated to appropriate personnel to inform them of serious trouble at the location of the truck so that authorities can be dispatched.

SYSTEM BENEFITS

More than 50 truckload motor carriers and others have implemented the OmniTRACS

system in part or all of their fleets and approximately 100 firms are currently evaluating the system. System benefits currently being experienced are: a) reduced telephone and other telecommunications expenses, b) increased revenue miles, c) reduced "deadhead" miles, d) reduced driver turnover, e) reduced accidents, and f) increased dispatch efficiency.

REFERENCES

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