N88-25707

MOBILESTAR FIELD TEST PROGRAM

WAYNE RUBOW, MOBILESTAR Program, Hughes Communications, Inc., United States.

Hughes Aircraft Company
P.O. Box 92919
Los Angeles, California 90009
United States

ABSTRACT

Systems currently under consideration for use in the Mobile Satellite System include Code Division Multiple Access (CDMA) and Frequency Division Multiple Access (FDMA) schemes. The choice between them is difficult because each approach has inherent advantages and disadvantages. The dissimilarity between the two approaches makes a direct comparison difficult and further complicates the choice. Initial studies have raised several questions which must be answered before an intelligent choice can be made.

Hughes Communications has performed various field tests in order to gain practical experience and a broader understanding of mobile communications. The field test program was divided into two main phases. The first phase consisted of CW propagation tests to develop firsthand experience of propagation phenomena. From this information, estimates of the feasibilty and accuracy of power control were possible. The next phase tested the idea of power control. Equipment representative of that expected to be used in an actual mobile satellite communication system was assembled and tested under a variety of environments.

TEST PROGRAM DESCRIPTION

A significant problem in communications between mobile platforms and satellites is multipath. As the mobile unit moves, reflected signals add destructively to the desired signals causing fading of signal strength. At the frequency of interest (L-band) this fading occurs frequently and results in deep nulls in the received signal power. To insure a reliable communications link despite such signal fading it may be necessary to apply a significant power margin. Satellite power is directly related to the cost, and a significant power margin could also adversly affect the maximum system capacity. Digital signaling techniques such as coding and interleaving can offer some resistance to the effects of multipath. In addition, CDMA has inherent multipath resistance qualities.

In all cases, (FDMA digital, FDMA ACSSB, or CDMA) a particularly important issue is that of power control. There are two types of fading that are of concern. "Fast fading", the result of multipath, can cause fading at rates between 100 to 300 times per second. This type of fading is uncorrelated over the frequency band spanning the receive and transmit frequencies. Because of the long satellite to earth propagation delay it is not feasible to control the effects of this type of fading through power control. Some coding and interleaving schemes are being evaluated as possible solutions to this problem.

PRECEDING PAGE BLANK NOT FILMED

Another type of fading is that which results from shadowing. This "slow fading" affects the average power and may be controlled to some extent by power control. This type of fading is critical to the CDMA access schemes. In a CDMA system the capacity of the system is limited by the Eb/Io (the ratio of the user's energy per bit to the co-channel user's energy). In the forward link (from the satellite to the mobile receiver) the fading due to shadowing is not critical because all of the signals from the satellite follow the same path and hence fade together. In this case the Eb/Io does not change and the system capacity is unaffected. On the return link however, (from the mobile unit to the satellite) each user's signal follows a different path. At any given time some of the users may be experiencing fading due to shadowing. Hence the Eb (energy per bit) produced by those users as seen by the satellite is reduced. In this case the Eb/Io for those users decreases. To combat this problem some margin must be given to Eb/Io to ensure that the users experiencing fading due to shadowing still have sufficient Eb/Io to communicate. This margin will directly reduce the capacity of the system (which of course reduces revenue).

The return link margin can be reduced if the mobile unit can provide uplink power control. Conceptually, the mobile unit radio would monitor the downlink (forward) power. When it detected a slow decrease in the average power due to shadowing it would increase the uplink (return) transmitter power to compensate. The test program evaluated the effectiveness of providing this power control.

In the FDMA system, satellite capacity is limited by the bandwidth and total forward link power. Forward link power control is desired to compensate for the variation in each mobile unit's signal requirements. The satellite antenna has a N-S variation over the coverage area of about 3 dB. The antenna gain vs. the direction of a mobile unit in Maine will be 3 dB less than the gain in the direction of a user in Kansas. Furthermore, the Maine mobile unit's antenna gain will be perhaps 2 dB less than its peak gain due to the low elevation angle to the satellite. The Kansas mobile user will have the peak antenna gain at its satellite elevation. The Maine user may require 5 dB more satellite power than the Kansas user.

The mobile users power requirements will also vary with terrain. In hilly terrain more power may be required to compensate for partial shadowing. It is therefore desirable for the satellite power on the forward link to be varied; however, because of the long delay in the two way satellite propagation, the forward link power would be corrected only a few times a minute.

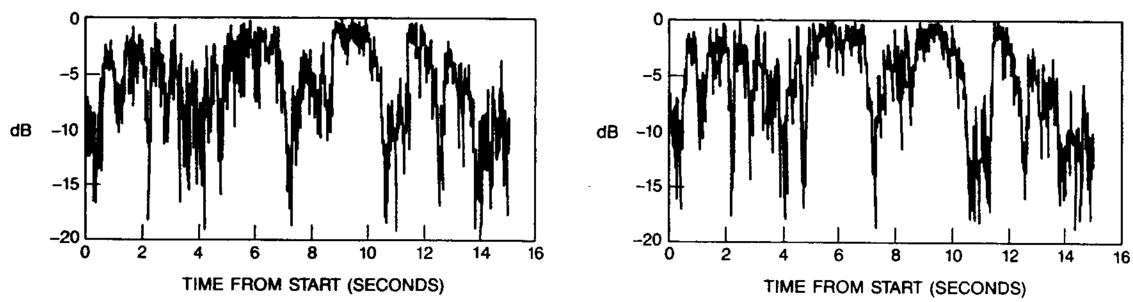
Regardless of which access scheme is chosen, some field testing was necessary. Modems representative of those to be used in the proposed system were built and field tested in a variety of typical mobile environments.

CW Propagation Tests

Lake Elsinore, CA, was chosen as the test site for the propagation tests because it provided typical mobile environments, both shadowing and doppler/multipath, and provided the highest available elevation angle in Southern California. The shadowing run that was selected was perpendicular to the hilltop transmitter site and provided approximately one-half mile of groupings of trees, which provided blockage, intermixed with areas of clear line of sight. The doppler/multipath run that was selected provided approximately one mile of clear line of sight with roadside trees, buildings, and other vehicles which provided sources of multipath interference. The elevation angle for the shadowing runs was approximately 15^{o}, and the elevation angle for the doppler/multipath runs varied from 8^{o} to 15^{o}.

Since the performance of the FDMA and CDMA schemes being considered is dependent on controlling the effects of slow fading, data on the fading characteristics were collected. The objective of the propagation tests was to characterize the power correlation properties between the expected uplink and downlink frequencies in order to determine the accuracy achieveable in uplink power control (in the case of CDMA) or downlink power control (in the case of FDMA), and to develop firsthand experience of propagation phenomena.

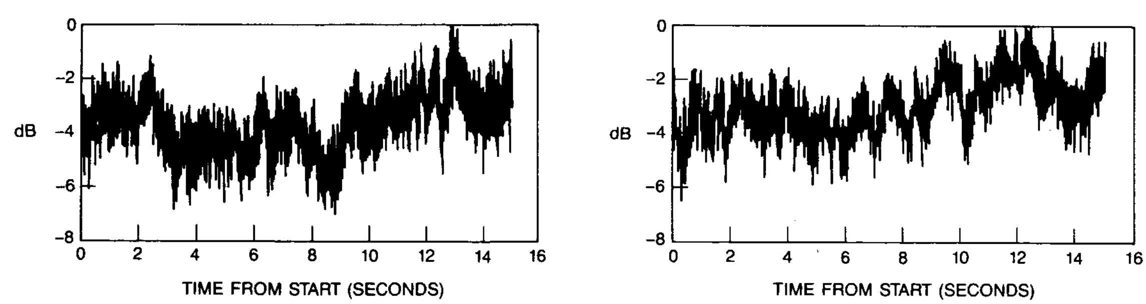
Typical propagation phenomena results of both shadowing and doppler/multipath environments are given in Figures 1 and 2, respectively. Analysis of these plots indicate that trees reduce signal power approximately 7 dB to 15 dB, depending on the type of tree, size of tree, number and density of branches. Some trees produced as much as 20 dB of blockage, and most trees produced at least 5 dB of blockage. Analysis of the doppler/multipath environment in Figure 2 indicates that multipath effects create approximately 3 dB signal variations. Simulation results tend to indicate that since these variations are uncorrelated between the uplink and downlink frequencies, power control of the multipath disturbances is not feasible.



CHANNEL A (1.5 GHz)

CHANNEL B (1.6 GHz)

Figure 1. Typical Propagation Phenomena: Shadowing Environment



CHANNEL A (1.5 GHz)

CHANNEL B (1.6 GHz)

Figure 2. Typical Propagation Phenomena: Doppler/Multipath Environment

In addition to performing test runs using the omni-directional droopy dipole antenna on the mobile vehicle, the directional helical antenna was also tested. Figure 3 shows the antenna comparisons with the mobile vehicle traversing the same run. Analysis of the propagation data in Figure 3 showing the antenna comparison indicates that the multipath contributions are much lower using a directional mobile vehicle antenna, while the shadowing losses are approximately the same.

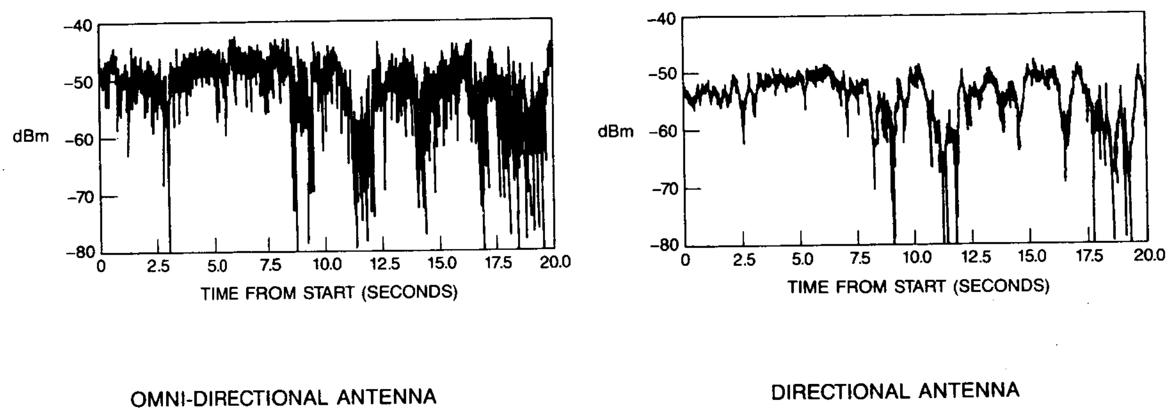


Figure 3. Antenna Performance Comparison

CDMA/FDMA Equipment Tests

The CDMA/FDMA equipment tests were a joint field test program which included participation by Hughes Communications, Inc. and the Canadian Department of Communications. The purpose of the equipment tests was to demonstrate the performance of three systems (FDMA digital, FDMA ACSSB, and CDMA) in actual mobile environments and to compare voice processing techniques in these environments. The performance of power control in the CDMA equipment was also tested. Demonstration of the performance of some of the above systems using both omni-directional and directional antennas was also desired.

The product of these tests was a video tape showing the automobile as it drove in both multipath and shadowing environments with a sound track of the transmitted speech. This video allowed a subjective comparison of the modulation techniques in field situations.

Since the system performance parameter (voice quality), which was used to compare one system to another, is somewhat subjective, appropriate steps were taken to insure that each system was initially calibrated to predetermined specifications. All of the testing used the same live speaker talking directly into telephone instruments in the automobile (as opposed to using a pre-recorded audio tape as the source).

The Canadian Department of Communications supplied the FDMA modems, both digital and ACSSB, along with a 2.4 kbps LPC-357 vocoder. The Canadian DoC also provided a directional antenna. Qualcomm, Inc., supplied the CDMA modems along with a 9.6 kbps RELP vocoder developed by M/A-COM and a 4.8 kbps vocoder developed by

Entropic, Inc.

Test runs at Lake Elsinore, CA, were selected which were representative of mobile system communication environments. These were the same test runs over which the propagation testing was performed. Table 1 describes the system/antenna combinations tested, along with the C/N_0 each system was initially calibrated for. The C/N_0 for the tests were as specified by the manufacturers. ACSSB was operated at the recommended 51 dB-Hz. The FDMA digital system was operated with a margin of about 8 dB above a 10^{-3} BER. The CDMA system was operated with a margin of 2 dB above a 10^{-3} BER.

Table 1. CDMA/FDMA Equipment Test List

System	Data Rate	Vehicle Antenna	C/No
CDMA	4.8 kbps	Omni-directional	41.5 dB-Hz
CDMA	4.8 kbps	Omni-directional	43.5 dB-Hz
CDMA	9.6 kbps	Omni-directional	41.5 dB-Hz
CDMA	9.6 kbps	Omni-directional	43.5 dB-Hz
FDMA ACSSB	N/A	Omni-directional	51.0 dB-Hz
FDMA ACSSB	N/A	Directional	51.0 dB-Hz
FDMA ACSSB	N/A	Omni-directional	48.0 dB-Hz
FDMA ACSSB	N/A	Directional	48.0 dB-Hz
FDMA digital	2.4 kbps	Omni-directional	48.0 dB-Hz

There were limitations to the test results. The 4.8 kbps and 9.6 kbps vocoders used with the CDMA modems were designed for operation in telephone systems under relatively constant signal strength and low bit error rate conditions. Some of the signal fading which ocurred in the shadowing runs exceeded the bit error rate operating range of these modems. When such a fade was encountered, the vocoders produced annoying "bleeps". The low elevation angles used during the testing intensified the shadowing and multipath effects.

CDMA/FDMA Equipment Test Conclusions. The end result of these tests was a VHS format video tape. Each system had pros and cons, and, since the results were subjective, opinion varied from individual to individual. Advocates of FDMA ACSSB and advocates of CDMA both believe that the tests proved superiority of their techniques. Although the results were subjective, some generally agreed upon conclusions can be stated.

- The FDMA ACSSB system proved to be very robust in severe shadowing environments. Large signal changes due to shadowing caused a loss of voice quality but maintained a degree of intelligibilty.
- In general, the subjective voice quality of ACSSB was generally considered to be less than that of the 4.8 kbps and 9.6 kbps digital voice.
- The CDMA system was able to operate effectively at 2 dB above a 10^{-3} BER, and was also able to operate effectively with 9.5 dB less C/N_0 than ACSSB.
- Above 30 mph, isolated trees did not cause appreciable voice degradation in either system.
- Shadowing by trees is generally much larger than a commercial operator would be willing to provide margin for.
- The voice quality of the FDMA ACSSB system with the omni-directional antenna was surprisingly better than when the directional antenna was used. Later analytical work

has indicated that there is a different propagation phenomena between using omni-directional and directional mobile vehicle antennas; however, no explanation of this anomaly is available at this time.

C-Band CDMA Equipment Tests

The equipment tests done at Lake Elsinore were tests using expected mobile communication environments; however, the hilltop transmission location merely represented the satellite. In order to get experience using an actual satellite, testing was performed using Galaxy II, a synchronous satellite located at 74° W. This provided an elevation angle of approximately 30°. This also provided the opportunity to assess the extent of shadowing on the Los Angeles freeway system.

Transmit equipment was located at the Fillmore, CA, earth station. Galaxy II, transponder 1, was used for the satellite link. The test vehicle was driven around the Fillmore area on freeways and rural streets for four hours. Interference from both other satellites and terrestrial microwave systems was rejected by the spread spectrum processing. The Qualcomm modems along with the Entropic 4.8 kbps vocoders were used for the tests. A 6 dB gain horn was used as the receive antenna. Simplex operation was established; voice transmission was from the Fillmore location to the mobile vehicle.

C-Band CDMA Equipment Test Conclusions. The performance of the CDMA modem with a C-Band link was very similar to that experienced at L-Band. If there was no shadowing, the speech was uninterrupted. The received voice transmission was the only test data recorded. Like the results of the CDMA/FDMA Equipment Tests, these results were also subjective. However, some generally agreed upon conclusions can be stated.

- Because there is very little shadowing on the LA freeway system, the system performance was near perfect, with full outages ocurring only under overpasses.
- The system performance on the rural streets was similar to that experienced at Lake Elsinore for the shadowing runs. The system was able to operate effectively at 2 dB above a 10^{-3} BER during line of sight conditions.

Hughes Communications extends their appreciation to John Lodge and Rob Milne of the Canadian Department of Communications for their participation in the CDMA/FDMA equipment test phase of these field tests.