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LAND-MOBILE FIELD EXPERIMENTS IN AUSTRALIA

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Abstract

The MSAT-X/AUSSAT experiment offered the first true land-mobile satellite configuration to evaluate the MSAT-X technologies and equipment. Both quantitative data tests and qualitative voice link demonstrations were successfully conducted. From the collected data, system performance in typical land-mobile conditions was extracted. A set of propagation characteristics corresponding to the wide range of environments encountered was also obtained. This article presents a brief description of the MSAT-X/AUSSAT experiment and a summary of its results analyzed to date.

1. Introduction

The Mobile Satellite Experiment (MSAT-X) has aimed to develop system concepts and high-risk technologies for land-mobile satellite communications. Pilot Field Experiments (PiFEx) have been conducted to meet the following objectives: 1) test and validate the subsystems of the MSAT-X mobile terminal; 2) characterize end-to-end system performance; 3) support design refinements and enhancements; and 4) demonstrate the viability of the system concept and technologies to users and manufacturers. The MSAT-X/AUSSAT experiment is the latest in the series of field trials. It was conducted in Australia between July 17 and August 2, 1989, and was the first field experiment where a true land-mobile satellite communications link was established.

2. PiFEx-- Background

Six field experiments have been conducted to date. The emphasis in the early experiments was on trouble-shouting and subsystem validation. The first three experiments: Tower 1 [1], Satellite 1a [2], and Tower 2 [3] took place in 1987. They were primarily aimed at validating the acquisition and tracking of the medium gain antennas developed in MSAT-X. Tower 3 was then conducted during the Summer of 1988 [4]. It was the first end-to-end test of the MSAT-X system in a simulated satellite environment. The MSAT-X/FAA/COMSAT/INMARSAT experiment was conducted in the winter of 1989. It successfully demonstrated both a fixed, ground and an aeronautical-mobile end-to-end satellite link [5]. Finally, the MSAT-X/AUSSAT experiment during the summer of 1989 offered the first true land-mobile satellite environment to test the MSAT-X technologies and equipment [6].

One further experiment is planned at this point. A Multipath Rejection Measurement Experiment (MRMEx) is scheduled for the summer of 1990. The ability of the directional antennas to discriminate against multipath signals, and thereby enhance system performance relative to an omni antenna, will be evaluated. Other experiments may be scheduled in the future as needed.

3. MSAT-X/AUSSAT Experiment Description

The experiment configuration is depicted in Figure 1. The set-up comprised a fixed hub station, the Japanese Experimental Technologies Satellite (ETS-V), and the mobile MSAT-X van. The hub station was located at the AUSSAT headquarters building in downtown Sydney. The van traveled between Sydney and Brisbane primarily along the coastline. This range of travel was dictated by the severe power limitations on the ETS-V satellite. During the experiment, the elevation angles at the van to the satellite varied between 51^o and 57^o.

Both data and voice tests were conducted. On the forward link, the hub station transmitted data at a frequency of 1646.70 MHz which the satellite translated to 1545.20 MHz for down-link transmission. On the return link, the van transmitted data at 1646.60 MHz which was retransmitted by the satellite at 1545.10 MHz. In either case, a pilot signal was also transmitted to the van at 1646.65 MHz which was then translated to 1545.15 MHz by the satellite. The pilot signal is required primarily for vehicle antenna tracking. It is also used to provided a reference for the receiver.

Both the hub station and van contained the basic communications terminal and other test and data acquisition equipment as appropriate to the site. The main components of the MSAT-X terminal are the speech codec, terminal processor, modem, transceiver, and directional antenna. Two directional antennas were tested. One is a low profile, mechanically steered tracking antenna developed at JPL and the other is an electronically steered phased array antenna developed for JPL by Teledyne Ryan Electronics (TRE). The directional antennas were used interchangeably on the van. In addition, an omni-directional antenna was placed on the van to provide some reference data during the experiment.

A data acquisition system (DAS) was provided in the van and the fixed station (hub). It recorded various system parameters and equipment outputs during the experiment. The data of primary interest is shown in Table 1 along with the sampling period and an indication of the site at which it was recorded. The power meter data are digital measurements of the received signal of the data channel. The Reference I and Q data are measurements of the pilot signal received through the omni-directional antenna. What is referred to as the Pilot I and Q data is the pilot signal received through either the JPL or TRE antenna. The terminal processor data contains information on the bit error rate (data link) tests performed. The compass X and Y data indicate the bearing (or direction) of the van. Unfortunately, the speed data was not recorded because the counter was inadvertently removed along with other unnecessary data acquisition equipment from previous experiments. Consequently, the propagation analysis presented here will cover signal probability densities and cumulative fade distributions, but will not include fade duration statistics.

4. Experiment Results

4.1 Propagation results

Although the primary focus of the experiment was on testing end-to-end system performance, typical propagation results were also obtained through post-experiment analysis.

Approximately 600 miles were covered by the van as it traveled from Sydney to Brisbane. Over this journey, a wide range of environmental conditions were encountered. There were periods with clear line-of-sight propagation to periods of moderate shadowing and to heavy shadowing as well. The van traveled along terrain that ranged from flat to mountainous. The roads also varied from straight to winding. This mixture of environments provided typical mobile conditions; i.e., conditions which may be encountered under normal operation of a mobile satellite communication system. Experimentation was not restricted to well-defined paths or areas with pre-selected characteristics.

Three typical received pilot signal profiles were observed at the van. Figure 2 shows the received signal during a clear line-of-sight condition. The constant overall signal level resembles an additive white Gaussian noise (AWGN) channel. A received signal through light to moderate shadowing is shown in Figure 3. As this figure shows, the duration of attenuation can last for several seconds at a time. Finally, the signal profile displaying a condition of heavy shadowing/multipath is shown in Figure 4. The discrete levels of attenuation apparent in Figure 4 are due to a combination of the low signal level being received in this shadowed environment and quantization effects in the DAS.

The cumulative fade distribution for these clear, light shadowing, and heavy shadowing/multipath environments are shown in Figure 5. On the clear channel, a fade level of 2.2 dB is experienced 1% of the time. A good portion of the fade is believed to be due to the noise present on the signal. The lightly shadowed channel experiences a 5.9 dB fade level 1% of the time. The heavy shadowing/multipath channel experiences a 12.5 dB fade level 1% of the time. In the heavy shadowing situation, the received signal is already experiencing about 2.6 dB of fade 90% of the time. This is due to the fact that the overall signal level is already undergoing a degree of attenuation and scattering. This takes place, for example, when the van passes by a continuous row of trees.

The probability density function for the received pilot envelope in the clear and the light shadowing conditions are shown in Figure 6. Unfortunately, insufficient data is available to obtain a comparable density for the heavy shadowing case. Also shown in Figure 6 is an analytically-derived Rician density that was fitted to the clear channel. The Rician K-factor (ratio of direct to scattered power in a multipath environment) is 16.5 dB. As mentioned previously, there is noise present on the pilot (approximately 42 dB.Hz C/N_0) and there is noise inherent in the data acquisition system, this is believed to be limiting the K value. The actual K value may be even higher. At a K of 16.5 dB (and higher values), the Rician density is already seen to be converging to the Gaussian shape. This reiterates the observation that the clear mobile channel, with a medium gain vehicle antenna and at a sufficiently high elevation angle, approaches an AWGN link.

4.2 System Performance Results

Data tests were performed to characterize the end-to-end system performance. A typical test consisted of transmitting 4000 contiguous blocks of 512 bits each. The system performance for stationary tests on the return link with the JPL antenna is depicted in Figure 7. Bit error rate (BER) performance in the field suffered approximately a 0.6 dB degradation compared to laboratory performance. Given the host of possible imperfections on the satellite link, the observed performance is well within expectation.

The mobile data tests are not as straightforward in their analysis as the stationary case. Significant signal fluctuations due to the changing environment, particularly deep fades due to occasional blockage, must be taken into account. The effect of such fades is shown in Figure 8 for a forward link test (similar effects are seen on the return link). The top plot is of the cumulative bit errors during a test. The corresponding received data channel power is also shown below it. This figure shows how an episode of brief but deep signal attenuation can lead to a disproportionate accumulation of bit errors. In other words, the contribution of such an event to the increase in bit error rate (BER) is not proportional to the resulting drop in signal-to-noise ratio averaged over the entire test. This phenomenon is natural in the mobile environment and arises often. Unfortunately, it complicates the extraction of system performance results.

Performance curves for mobile tests on the return link are shown in Figure 9. Curves for both the JPL and TRE antennas are shown. They show that link performance under generally clear conditions was approximately 8.5 to 9.3 dB E_b/N_0 to achieve a BER of 10^{-3}. Thus, performance in the field is within approximately 1 dB from the performance in the lab. This, again, is well within expectation.

4.3 Qualitative Observations

In addition to the essentially one-way data tests, two way voice communications were established and used often between the experimenters in the van and the hub. A variety of recorded standard voice test material was also used for post-experiment evaluation. As an example of outstanding system robustness, a two-way voice link was established and maintained for two hours through a variety of propagation environments. No loss of modem synchronization occurred and only occasional, brief periods of silence were experienced.

5. Conclusions

The MSAT-X/AUSSAT experiment was successfully completed. Characterization of the system performance under typical mobile conditions which are not rigidly controlled was achieved. A variety of land-mobile environments were encountered and characterized. With a medium gain antenna, and at 51^o - 57^o elevation angles, the clear condition closely resembles an AWGN channel. When deep fades are encountered, the errors induced by such events tend, as expected, to dominate the overall error rate performance.

The field performance of the data links under mobile and stationary conditions was less than 1 dB from laboratory (stationary) performance. Good voice quality and a high degree of robustness were also demonstrated on the voice links. In all, the MSAT-X terminals performed very well in the land-mobile environment.

References

1. MSAT-X Quarterly, No. 13 (Special Issue), JPL 410-13-13, January 1988.

2. J. B. Berner, "The Pifex Satellite 1a Experiment," MSAT-X Quarterly, No. 15, JPL 410-13-15, June 1988.

3. J. B. Berner, "The Tower 2 Experiment," MSAT-X Quarterly, No. 15, JPL 410-13-15, June 1988.

4. K. Dessouky, T. C. Jedrey, and L. Ho, "Summary of Results From The Tower 3 Experiment," MSAT-X Quarterly, No. 20, JPL 410-13-20, July 1989.

5. T. C. Jedrey, K. Dessouky, and N. E. Lay, "An Aeronautical Mobile Satellite Experiment," JPL report to be published Summer 1990.

6. T. C. Jedrey, and W. Rafferty, "The MSAT-X/AUSSAT Land-Mobile Satellite Experiment: An Overview," MSAT-X Quarterly, No. 22, JPL 410-13-22, Jan. 1990.

Table 1. Partial List of Recorded Data

ITEM	DESCRIPTION	SAMPLING PERIOD	VAN	HUB
1	TIME TAG	3.75 sec	X	X
2	POWER METER	3.75 sec	X	X
3	REFERENCE I & Q	1 msec	X	
4	PILOT I & Q	1 msec	X	
5	TERMINAL PROCESSOR	30 msec	X	X
6	COMPASS (Y)	30 msec	X	
7	COMPASS (X)	30 msec	X	
• • •	SEVERAL OTHER PARAMETERS • • •	• • •	• • •	• • •

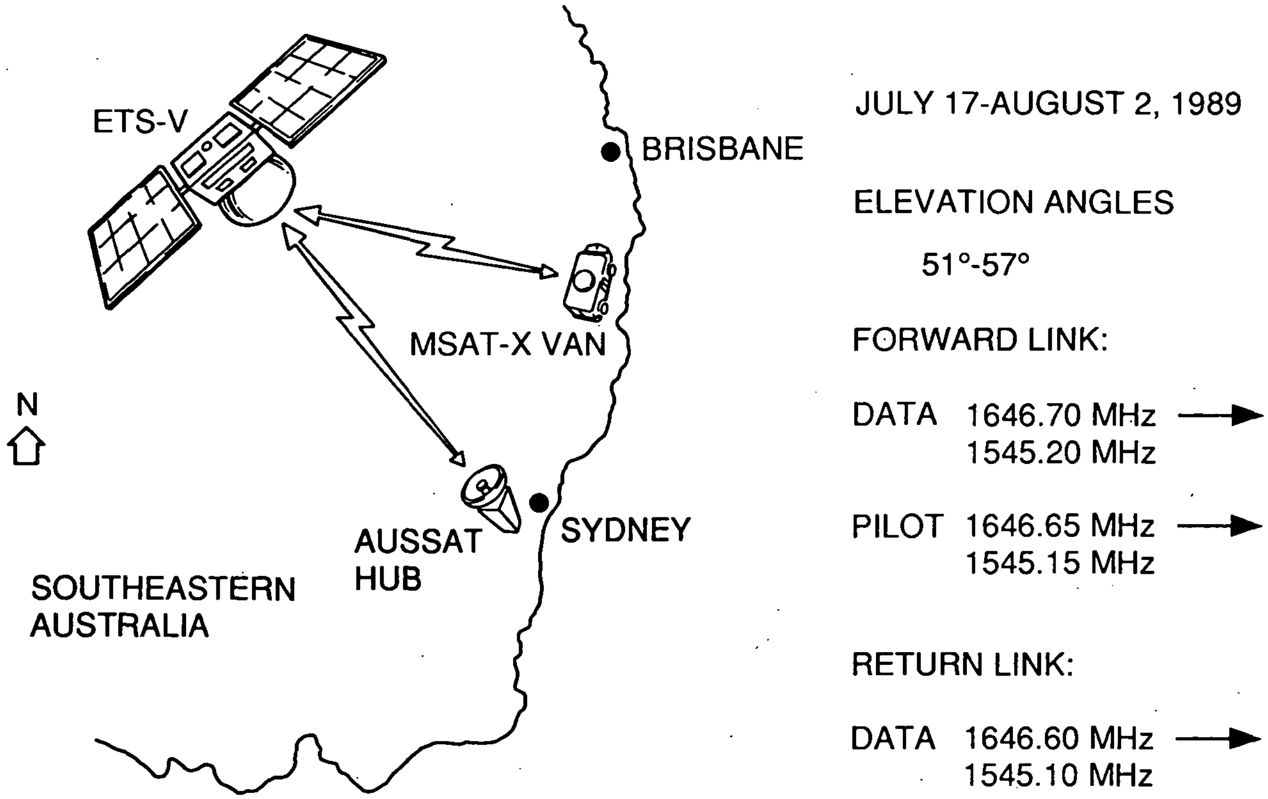

Figure 1. MSAT-X/AUSSAT Experiment Configuration

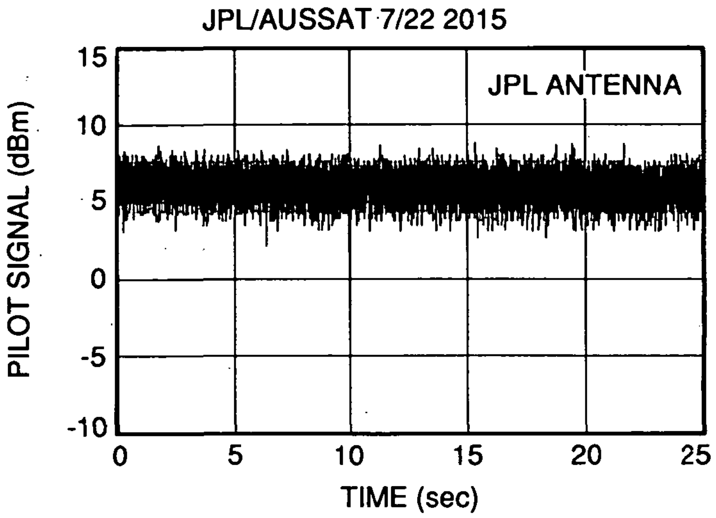

Figure 2. Received Pilot on a Clear Channel

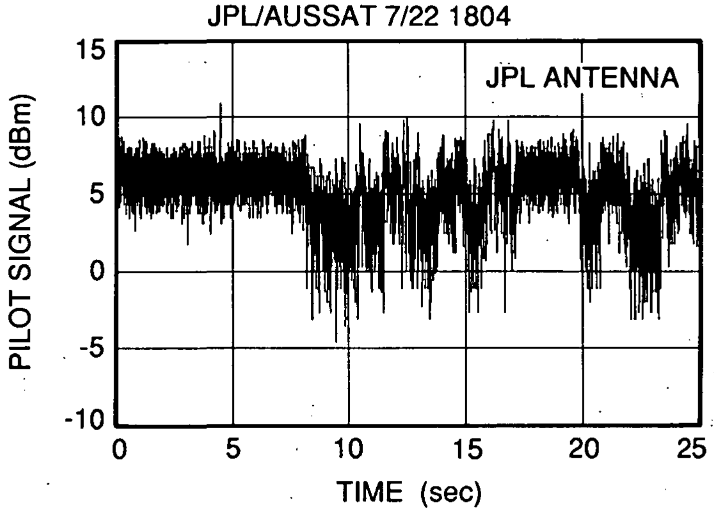

Figure 3. Received Pilot with Light/Moderate Shadowing

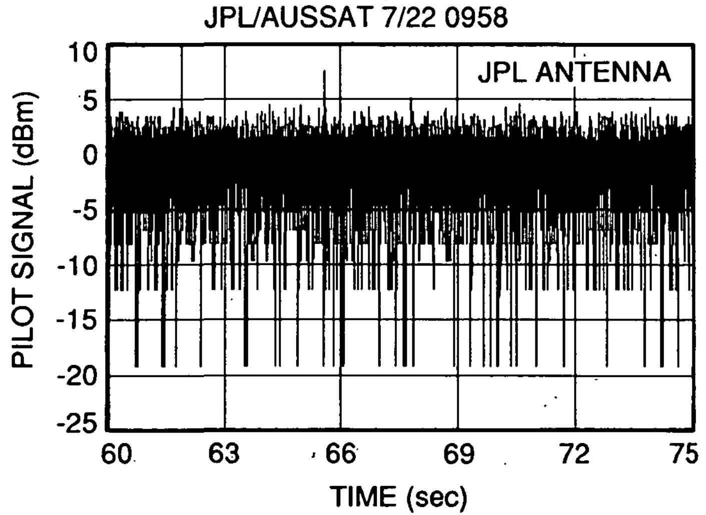

Figure 4. Received Pilot with Heavy Shadowing/Mulitpath

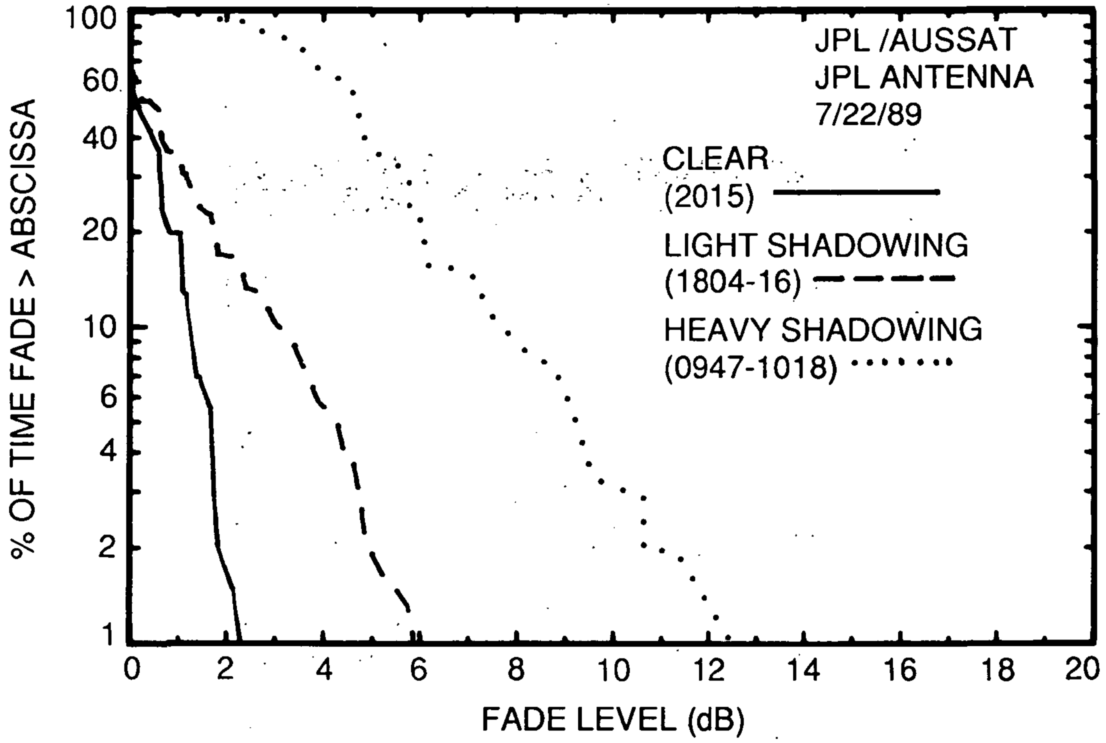

Figure 5. Cumulative Fade Distribution of Received Pilot in Different Environments

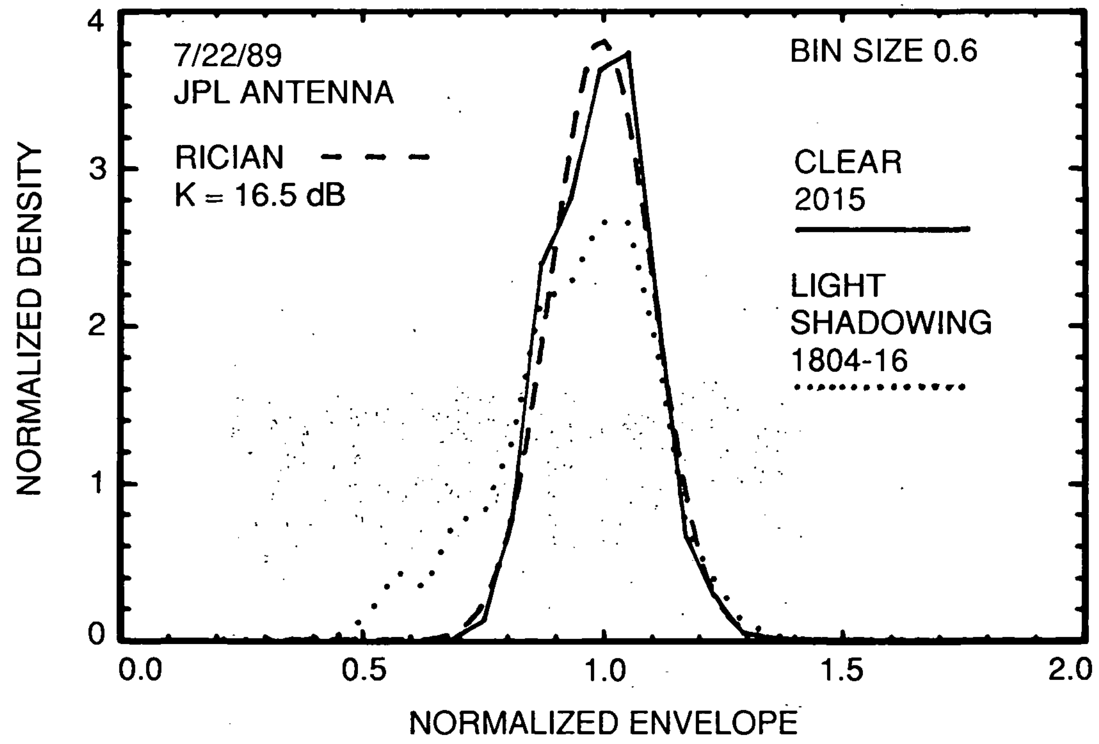

Figure 6. Probability Density Functions for Envelope of Received Pilot

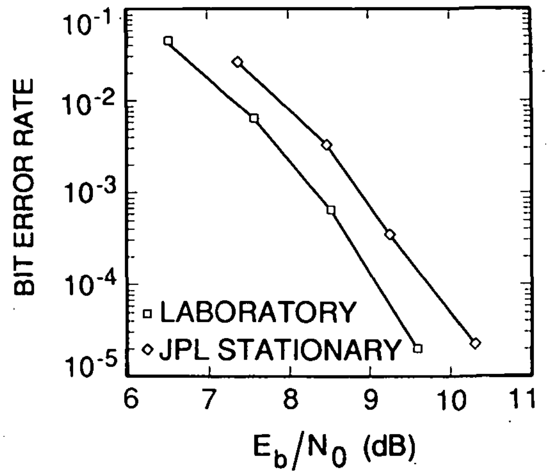

Figure 7. System Performance During Stationary Tests

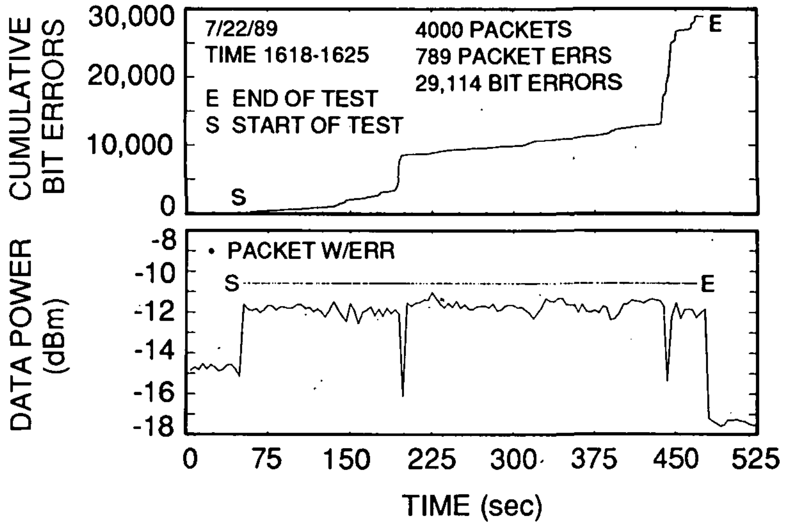

Figure 8. Cumulative Bit Errors and Received Data Channel Signal Power During a Mobile Test

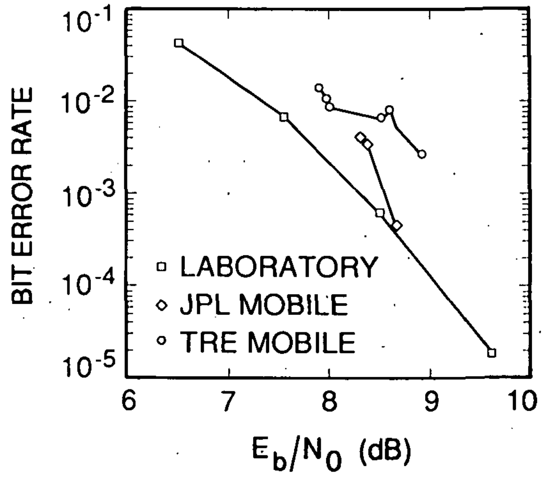

Figure 9. System Performance During Mobile Tests