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LAND MOBILE SATELLITE PROPAGATION RESULTS

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ABSTRACT

During the Fall of 1987, Rockwell International in cooperation with COMSAT General and INMARSAT performed a land-mobile satellite demonstration using the MARECS B2 satellite at 26 degrees W. During this demonstration a van equipped with a satellite transceiver, a 1.8-inch monopole antenna, a demonstration computer system, and both LORAN-C and GPS navigators was driven over 2,000 miles in the Northeastern and Midwestern United States. Elevation angles to the satellite were 7 to 22 degrees. A narrow-band 200 b/s full-duplex data channel was demonstrated in a half-duplex protocol in which the van responded to an interrogation from the base station computer at Southbury, Connecticut through the satellite every two or three seconds. Results were summarized along with position approximately every two minutes. Messages ranged from 40 to 67 bits with continuous fill transmitted between messages on the base-to-mobile link. Burst transmissions of similar size preceded by 88-bit preambles were used on the mobile-to-base link. The overall success rate on 42,974 transactions during a trip from Cedar Rapids, Iowa, to Washington, DC, and back was 92.4 percent on the satellite-to-mobile link and 75.4 percent on the mobile-to-satellite link, for a combined poll-response success rate of 69.6 percent.

INTRODUCTION

During September, October, and November 1987 a two-way data communications experiment was conducted between an instrumented van and a simulated dispatch station. The dispatch station was connected by dial-up telephone link to a base station computer located at COMSAT General's Maritime Services Coast Earth Station at Southbury, Connecticut. A two-way 200 b/s full-duplex radio link was then established through the INMARSAT MARECS B2 satellite located at 26 degrees West longitude to a mobile van. A half-duplex protocol simulated a future lower-cost, half-duplex mobile unit.

The route of the experiment is depicted in Figure 1, which also shows elevation angles to the satellite. The general purpose, system configuration, and overall results of the experiment are discussed in [1]. The modem is discussed in [2]. Overall propagation performance results and preliminary detailed results are discussed below.

SYSTEM DESCRIPTION

For purposes of the propagation experiments the forward link of the system may be characterized as transmitting a continuous 200 b/s data signal through the satellite. The satellite broadcasts this signal to the coverage area at the experimental frequency of 1541.3 MHz along with the other traffic in the system. The minimum power at the satellite corre-

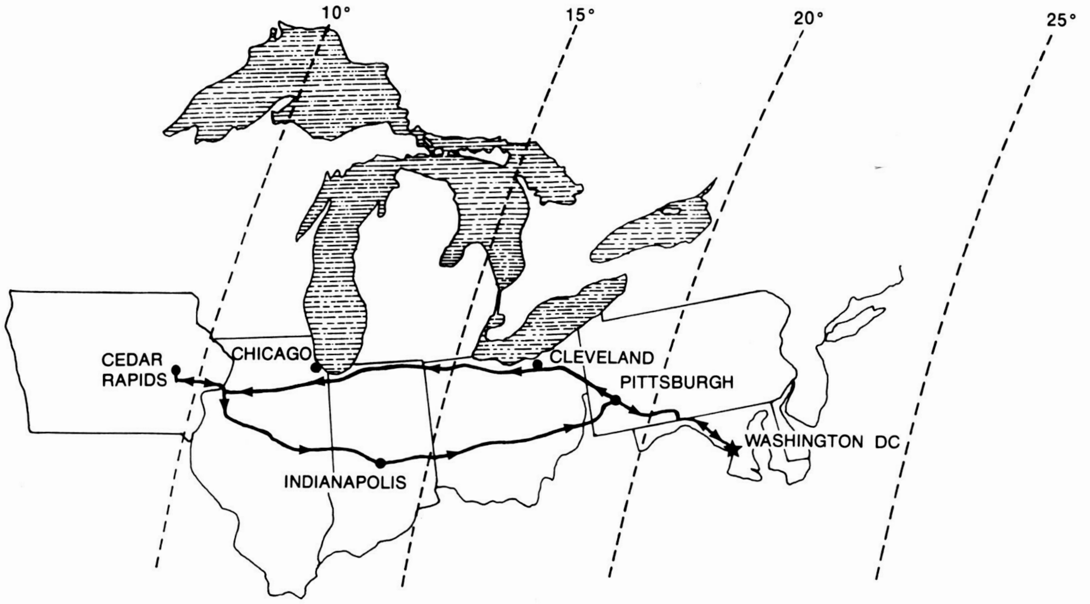

Fig. 1. Map of demonstration route

sponds to 24 dBW EIRP which is the power normally assigned to four "standard-A" channels. A standard-A channel is normally used with a three-foot steerable parabolic antenna on a ship to provide FM voice service in a 50-kHz channel.

For the eastbound trip, the mobile unit utilized a 1.8-inch monopole antenna over a 12-inch square ground plane. Due to a mechanical failure, a Dorne-Margolan Model DMC146-2-1 GPS antenna was pressed into service for the return trip. These were mounted on a passenger van type vehicle and are shown in Figures 2 and 3. It is probable that the monopole antenna pattern is uniform in azimuth, and has a fairly broad peak in elevation beam width with 3-dB points around 10 to 50 degrees elevation angle. It provides a peak gain of perhaps 4 dB for vertically polarized signals but theoretically incurs a 3-dB penalty for the circularly polarized INMARSAT signal. See [3] for example.

Hence, the transmit and receive power budgets shown in Table 1 reflect a 0-dB gain antenna for the vehicle.

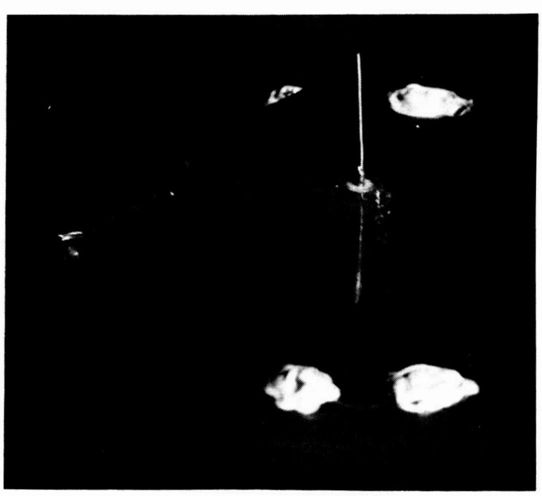

Fig. 2. Monopole antenna

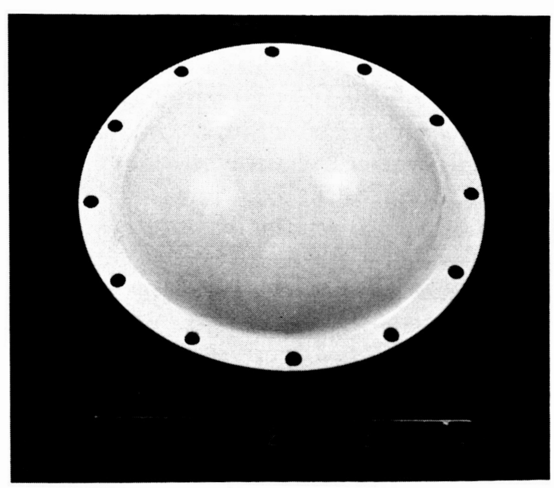

Fig. 3. Crossed curved dipole antenna

Table 1. Power budgets

FORWARD LINK

CES to Satellite

6.42 GHz. El. Angle 22.7°, d = 31.130 km
CES EIRP 64 dBw
Path loss = 200.9 dB
Absorption loss = 0.4 dB
Satellite G/T = -15 dB/K
Mean uplink C/N_0 = 76.3 dB
Mean sat C/I_0 = 58.4 dB

Satellite to Mobile

1.54 GHz, El. Angle 10°, d = 42,440 km
Satellite mean EIRP = 24 dBw
Path loss = 188.8 dB
Absorption loss = 0.4 dB
Mobile G/T = -27 dB/K
Mean downlink C/N_0 = 36.4 dB
Interference loss = 0.5 dB
Total RSS random loss = 1.5 dB
Overall C/N_0 = 34.4 dB
C/N (200 Hz) = 11.4 dB

RETURN LINK

Mobile to Satellite

1.64 GHz, El. Angle 10°, d = 42.440 km
Mobile EIRP = 14.7 dBw
Path loss = 189.3 dB
Absorption loss = 0.4 dB
Sat G/T = -11 dB/K
C/N_0 = 40.9 dB
Sat C/I_0 = 49.7 dB
Tpdr gain = 150.9 dB

Satellite to CES

4.2 GHz, El. Angle 22.7°, d = 41,130 km
Sat EIRP = -25.8 dBw
Path loss = 197.19 dB
Absorption loss = 0.5 dB
CES G/T = 32 dB/K
Mean downlink C/N_0 = 37.11 dB
Mean downlink $C/N_0 + I_0$ = 35.4 dB
Interference loss = 0.5 dB
Total random RSS loss = 1.35 dB
Overall C/N_0 = 33.55 dB
200 Hz = 23 dB
C/N (200 Hz) = 12.2 dB

Several circularly polarized antennas were procured, tested, and resulted in poorer performance than the monopole antennas in prior laboratory tests. These tests included the antenna actually used on the return trip. It is theorized that this may be due to the loss of the horizontal component of the received wave due to low elevation angles, poorer matching, or losses in these larger, more complex antennas.

The return trip antenna has maximum gain at the zenith and is characterized as having at least -2 dBic gain at all angles above 5 degrees for the GPS frequencies. It is a circularly polarized crossed dipole with the arms curved to fit the interior of a 4-inch hemispherical radome.

The power budgets reflect a higher carrier to noise ratio for the return link than for the forward link, yet the forward link was more reliable. This may be due to extra actual forward link power, to the superior performance of the modem on the continuous forward link signal, or to slightly greater interference and noise problems on the return link.

A companion paper [2], discusses the modem in detail. Unshaped (square) 180-degree differential phase shift modulation is used. The modem is designed to rapidly acquire the 200 b/s signal in an initial acquisition bandwidth of about 2000 Hz. Thus, in acquisition, the signal-to-noise ratio is about 10 dB worse than during tracking. As explained in the companion paper, the modem produces a bit error rate of 10^{-3} at a signal to noise ratio of about 8 dB. For the burst transmission on the return link a preamble of 88 bits was most often used. The modem requires a minimum preamble of about 40 bits, but results improve with preamble length, especially with high noise.

For purpose of the propagation experiments, the base station interrogates the mobile unit with a packet of meaningful data 42 to 67 bits long imbedded in a continuous 200 b/s signal which is mostly filler. This normally occurs every three seconds. The mobile unit then responds with a burst of data at 1642.8 GHz consisting of an 88-bit preamble followed by a similar variable length packet of 42 to 67 bits.

Each packet contains a 16-bit cyclic redundancy check (CRC) code. Messages with CRC errors are ignored functionally and scored as a nonsuccess in the propagation statistics. Thus, unless the CRC checks perfectly on the interrogation, the mobile unit does not respond. If a multisegment transaction is involved, the next interrogation occurs as fast as possible after a successful response. This maximum rate is about two seconds per transaction due to transmission times and processing and propagation delays.

EXPERIMENTAL RESULTS

As shown in Figure 1, the vehicle was driven at various times from as far West as Pella, Iowa (about 7 degrees elevation angle) to Washington, DC (about 22° elevation angle) through Indianapolis, Indiana. It returned via a more northerly route through Cleveland, Ohio, and Chicago, Illinois. In addition, several side trips were made within Iowa. During most of this time both LORAN-C and Global Positioning System (GPS) position data were available. Propagation data were summarized every two minutes on disk in the mobile unit computer and in the base station computer at Southbury, Connecticut. The Southbury data were then transmitted nightly via modem to the dispatch station, usually at Cedar Rapids, Iowa. Mobile unit disks were physically returned to Cedar Rapids.

While the base station report alone provides the overall round trip success of the transactions, the mobile unit report allows one to separate the performance of the satellite-to-mobile link from the performance of the mobile-to-satellite link.

The statistics in Figure 4 show the results for two minutes of September 30, 1987, on a trip from Cedar Rapids to Pella, Iowa, in flat terrain on Intersate 80 headed West at the position shown which is near highway mile marker 205. The statistics cover the period from 1:58 to 2:00 PM CDT on the van which is the interval from 2:58 to 3:00 PM EDT at the base station in Southbury, Connecticut.

During this time the base station interrogated the mobile unit 49 times and received 44 responses with correct CRC codes. The mobile unit received and responded to 47 messages. Thus, in this case 2 messages were lost on the forward link and 3 more were lost on the return link. Of the three lost responses, unique words were correctly received for two of these, as indicated by CRC errors while the other was lost entirely. Successful responses (S) and unsuc-

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TIME     02:00 PM  GPS time       MOBILE  UNIT
  GPS LAT      41   41' 45" N      GPS LONG      92   18' 09" W
LORAN LAT      41   41' 58" N    LORAN LONG      92   17' 34" W
SEGMENT TYPE         0        1       5        6      7     TOTAL
# Transmits         12        5       0       30      0        47
# Received           5        0       0       29     13        47
# Retransmits        2        0       0        0      0         2
# CRC Errors                                                    2
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Mobile Unit Statistics

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TIME     03:00 PM  GPS time       BASE  STATION
  GPS LAT      41   41' 45" N      GPS LONG      92   18' 09" W
LORAN LAT      41   41' 58" N    LORAN LONG      92   17' 34" W
SEGMENT TYPE         0        1       5        6      7     TOTAL
# Transmits          5        0       0       29     15        49
# Received          10        5       0       29      0        44
# Retransmits        0        0       0        1      4         5
# CRC Errors                                                    2
SSSSSSSSSSSSSRSSSRRRSSSSSSSSSSSSSSSSSSSSSSSSSRSSSSSSS
TOTALS SINCE STARTING
          2647  Transmitted                   1884  Received
           403  Retransmitted                  107  CRC Errors
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Base Station Statistics

Fig. 4. Two minute reports

cessful responses resulting in a retransmit (R) are shown in Figure 4 as a string of 49 characters in the base station statistics. These message totals are composed of five message types 0, 1, 5, 6, and 7 ranging in length from 42 to 67 bits.

October 8, 1987, is considered in detail. This is a route segment from Indianapolis to Pittsburgh. There were 7847 interrogations and 4715 successful responses for an overall success rate of 60.1 percent. In terms of individual link performance, 7137 interrogations were received by the mobile, so that overall forward link performance was 91.0 percent and reverse link performance was 66.2%.

At a higher level of detail Figure 5 shows the overall round trip success rate for the 153 reports covering the Indianapolis to Pittsburgh portion of the trip on October 8, 1987, from 1:15 PM to 7:15 PM EDT. Most would be two-minute reports. Note that the success rate varies from 100 percent to near zero. A linear regression superimposed on the data shows that the overall success rate was about 85 percent near Indianapolis decreasing during the day to 55 percent near Pittsburgh reflecting a change in the terrain. A 10-point moving average is also shown.

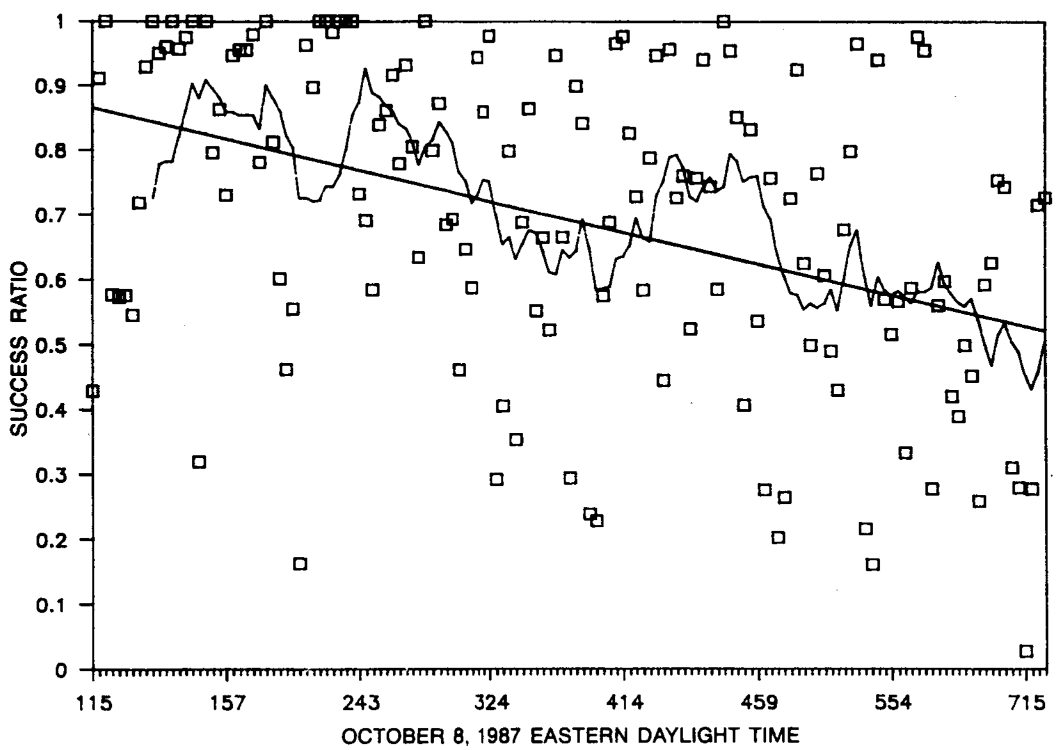

Fig. 5. Indianapolis to Pittsburgh results

At a finer level of detail yet Table 2 presents a fourth order Markov model for the success of a transaction given the history of the previous four transactions. Reduced order models are also shown.

We see that propagation failures are clustered — so are buildings and trees.

Finally, Figure 6 shows the overall round trip on October 7, 8, and 9, 1987, eastbound and October 26, 27 and 28, 1987, westbound. The antenna change occurred between the East and West legs. The probability of a round trip success for the 42,974 transactions covered by 853 two-minute reports is shown as a 10 point moving average (about 20 minutes) and also as a linear regression. Figure 7 separates the forward (upper curve) and return link individual success probabilities in the form of 30 point (about one hour) moving averages for the same data.

Table 2. Conditional probabilities of success — percent

Order 4	3	2	1
SSSS 89.18	SSS 88.49	SS 86.10	S 82.69
SSSR 66.23	SSR 62.12	SR 55.27	R 28.89
SSRS 78.68	SRS 75.34	RS 66.42	
SSRR 38.92	SRR 35.18	RR 18.18	
SRSS 75.60	RSS 71.27		
SRSR 55.45	RSR 41.70		
SRRS 59.06	RRS 55.40		
SRRR 23.50	RRR 14.40		
RSSS 83.20			
RSSR 51.95			
RSRS 65.49			
RSRR 30.38			
RRSS 64.00			
RRSR 32.30			
RRRS 53.42			
RRRR 12.87			

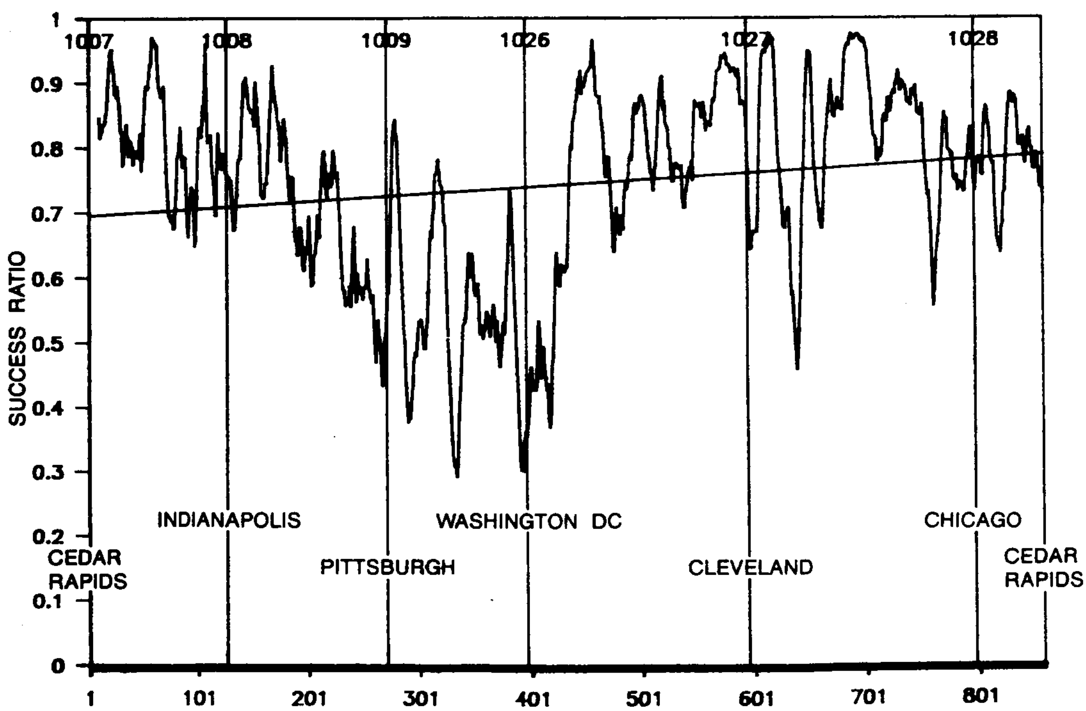

Fig. 6. Two-way success ratio - two minute intervals - 10 point moving average

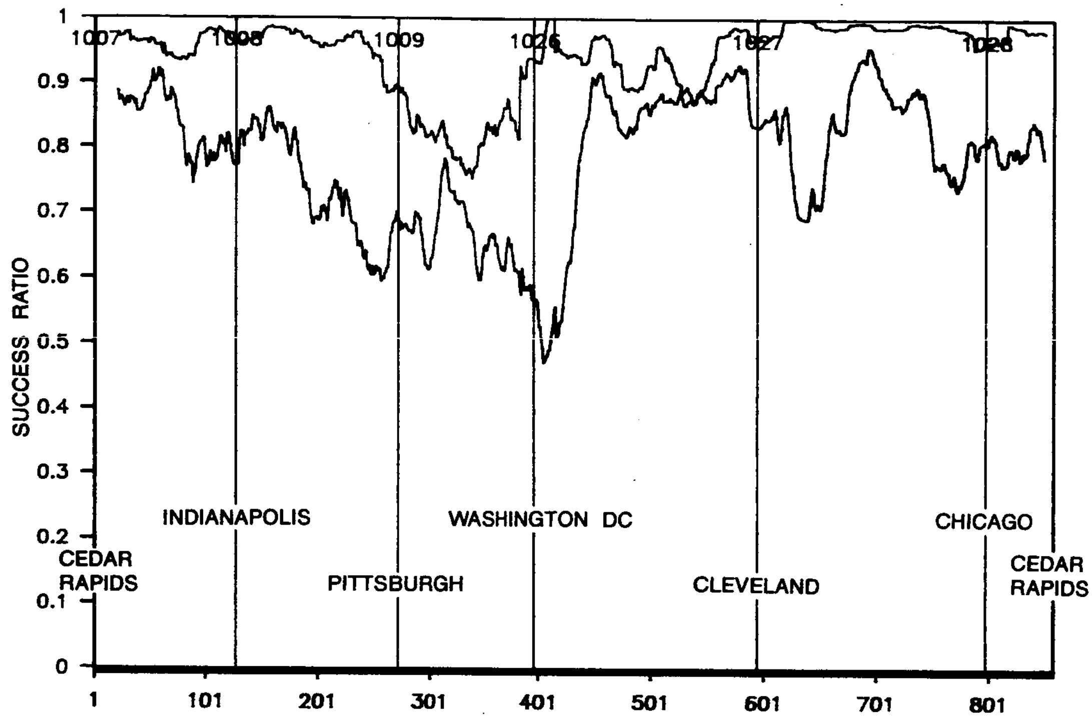

Fig. 7. Forward (upper) and return (lower) link success ratios - 30 point average

OBSERVATIONS

While all the data have not been digested, some observations are in order. First, the system worked remarkably well for the margins indicated. Second, when the system worked poorly, the experimenters could almost always identify terrain or other obstacles casuing blockage. Third, the forward link seems relatively more reliable than the return link, and occasional return link problems occurred which have not been entirely explained.

ACKNOWLEDGEMENTS

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