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MOBILE RADIO ALTERNATIVE SYSTEMS STUDY

EXECUTIVE SUMMARY

JUNE 1983

PREPARED FOR

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General Electric Company
Corporate Research and Development
Schenectady, New York

Roy E. Anderson

INTRODUCTION

The Mobile Radio Alternative Systems Study addressed the needs for mobile radio communications in non-urban areas of the United States between the present and the end of this century. It evaluated terrestrial and satellite technologies and systems to determine how those technologies and systems might be applied to satisfy the needs. This report summary is generally organized according to the tasks of the study, which were to:

1. Define a nationwide land-mobile traffic model for the period 1985 through 2000 and define the functional and system requirements necessary to meet those projected needs.
2. Define an optimized terrestrial system to satisfy the requirements for nationwide land mobile services and estimate system characteristics, costs, and subscriber charges.
3. Identify the role of a mobile-satellite system in augmenting the terrestrial system and define an optimized satellite/terrestrial (hybrid) system.
4. Identify and analyze regulatory and institutional issues relative to the implementation of the hybrid system.

The study results show that there are needs for mobile radio services in non-urban areas that are not likely to be met by a continuation of the traditional growth of mobile radio. The services include nationwide (ubiquitous) radio telephone, dispatch, wideband data, one and two way exchange of short, infrequent data and control messages and position surveillance.

Terrestrial radio links are limited in range by the earth's curvature and shadowing by terrain features so that nationwide coverage would require many terrestrial fixed installations. A complex interconnection of the installations would be required to provide the needed services in thinly populated areas. The short range of terrestrial installations enables a radio channel to be used simultaneously in many different geographical locations. Frequency "reuse" makes it possible to accommodate large numbers of users within a limited spectrum allocation.

Satellite links are distance insensitive so that thinly populated and remote areas can be served effectively. The large service area of satellites limits frequency reuse and thus the number of users within a frequency allocation. Satellites are not well suited to densely populated areas.

Most users of mobile radio will be served by terrestrial systems because they operate predominantly in densely populated areas or their range of travel is limited to the coverage area of a terrestrial installation. Entities that operate vehicles that travel over long distances, or into remote areas, such as trucks and oil well service vans, may be better served by a satellite system.

The study concludes that there is a significant market for satellite mobile service and a satellite system can be built to serve the market at acceptable user charges. The criteria of the Federal Communications Commission for allocating radio spectrum is discussed.

Section 1

MOBILE RADIO TRAFFIC DEMAND NON-URBAN UNITED STATES, 1985-2000

MARKET CATEGORIES AND MAGNITUDES

The potential market for non-urban land mobile radio is divided into three categories:

- New Services
- Commercial and Public Radio
- Mobile Radio Telephone

New services are herein defined as those for which there are expressed needs but which are not now met by any application of available technology. The functions required to fulfill the needs include voice, alphanumerics (printed messages), data at rates from 300 bits per second to 56 kilobits per second, and automatic surveillance of mobile locations.

The commercial and public services market is drawn from the existing users of mobile radio in non-SMSA areas of the country.[1] Most of the communications are in the dispatch mode — direct communications between mobiles and base stations. Most users are satisfied with the performance of their radios. A portion of the users express dissatisfaction with the coverage area of their radios because their communication range is too short or because terrain features block out their signals in portions of their service area.

There is a substantial market for mobile radio telephone in thinly populated areas of the country. A market survey by Opinion Research Corporation[2] was used to estimate the number of persons who would subscribe to mobile telephone service in the non-SMSA counties of the contiguous United States if the quality and cost of the service were like those of urban cellular systems. The capturable market for each of the market categories is shown in Tables 1 through 4.

GEOGRAPHICAL DISTRIBUTION OF DEMAND

The geographical distributions of demand for Mobile Radio Telephone service and Commercial and Public Radio services are critically dependent on the population density that is assumed for the definition of the non-urban area of the country. If the non-urban area is defined as the non-SMSA counties, the distribution for mobile telephone service is as shown in Figure 1. If the non-urban area is defined as those counties that have a population density fewer than 20 persons per square mile, the distribution is as depicted in Figure 2. The distribution for commercial and public radio is very nearly the same as for mobile telephone because the demand for both is determined mostly by population.

The choice of 20 persons per square mile results in the largest demand in the Western states. Choosing non-SMSA counties as the non-urban definition results in the greatest demand in the Midwestern states with a much smaller proportion in the West.

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[1] Much of the data and procedures for market analyses were provided by ECOsystems International under a subcontract to this study. Their portion of the study is presented in: *Non-Urban Mobile Radio Market Forecast,* Final Report, June 25, 1982 ECOsystems International Inc., P.O. Box 225, Gambrills, MD 21054.

[2] "An Appraisal of a Mobile Communications Product for the Consumer," Conducted for Audio Electronics Department of General Electric Company, Prepared by Opinion Research Corporation, North Harrison Street, Box 183, Princeton, NJ 08540

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Table 1

CAPTURABLE[1] MOBILE RADIO MARKET (MOBILE UNITS) NEW SERVICES

Oil and Gas Industry[2]	1990[4]	(AAGR[5])	1995	(AAGR[5])	2000
Voice (Base of 16002[3])	35736	(3%[6])	41428	(3%[6])	48626
Data (Base of 3629[3])	7288	(3%[6])	8449	(3%[6])	9794

1. Capturable Market—The market for new mobile systems based on their provision of new services at prices comparable to current service charges for inferior or largely nonexistent services.
2. One of two market areas surveyed.
3. The base comes from a study done for NASA by ECOsystems International Inc. titled "Analysis of the Oil and Gas Industry Market for a Land Mobile Communications Satellite Service," January 18, 1982. ECOsystems forecasts a gross market of 28,000 units by 1985. This is equivalent to an average annual growth rate of 15% per year for the period 1981-1985. We employ this gross figure for our computations for the voice demand. However, since there has recently been a slump in drilling activity and most of the data requirements are for logging new wells we have performed a separate analysis for the data requirements. We assume that the average annual growth rate for the number of units is 12% for the period 1981-1985. This rate is equivalent to the growth in exploration units and equals the pre-1980 growth in active drilling rigs (cf. "Oil and Energy Trends," July 1982). For both voice and data we assume a common annual growth rate of 5% for the period 1985-1990 to obtain the number of units for the year 1990. (We assume that to some extent the drilling slump continues.)
4. We assume that there is essentially a 100% penetration of the market by 1990.
5. Average annual growth rate.
6. We assume that the market is approximately saturated in the period 1990-2000 and a common annual growth rate of 3% to the year 2000.

Table 2

CAPTURABLE[1] MOBILE RADIO MARKET (MOBILE UNITS) NEW SERVICES

Trucking Industry[2]		1990[4]	(AAGR[5])	1995	(AAGR[5])	2000
Trailer	(Base of 153942[3])	168 439	(2%[6])	185 970	(2%[6])	205 326
Tractor	(Base of 79421[3])	86 900	(2%[6])	95 945	(2%[6])	105 931

1. Capturable Market — The market for new mobile systems based on their provision of new services at prices comparable to current service charges for inferior or largely nonexistent services.
2. One of two market areas surveyed.
3. The base comes from an analysis of financial and statistical data for the year 1979 from the Financial and Operations Statistics Manual published by the American Trucking Association and Moody's Transportation Volume. The total annual revenues of the common and contract carriers that engage in irregular long haul routes is $11,169,000,000 (general freight common, household goods, and special commodities common and contract; ATA manual). A random sample of 34 common and contract irregular route carriers as reported in Moody's shows total revenues of $1,516,000,000 for 20,895 trailers and 10,780 tractors. The revenue per trailer is thus $72,553 and there are 1.9383 trailers per tractor on average. Using these statistics and the total revenues one obtains the base.
4. We employ an annual growth rate of 2% (from a study done for NASA by ECOsystems International, Inc. titled, "Analysis of the Trucking Industry Market for a Land Mobile Communications Satellite Service," January 11, 1981) and an in-service factor of 88% (supplied by an industry representative) to obtain the number of units in 1990. Also based on the ECOsystems study we assume that there is essentially a 100% penetration of this specific market by the year 1990.
5. Average annual growth rate.
6. We employ a growth rate of 2%. See footnote 4.

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Table 3

CAPTURABLE[1] MOBILE RADIO MARKET (MOBILE UNITS) COMMERCIAL AND PUBLIC RADIO SERVICES

Possible Base Market[2]		(AAGR[6]) (1980-1990)	1990	(AAGR[6])	1995	(AAGR[6])	2000
Conservative:	56 599 (5% of base)	(7%[7])	111 339	(7%[7])	156 159	(7%[7])	219 021
Likely:	169 798 (15% of base[4])	(10%[8])	440 412	(10%[8])	709 288	(10%[8])	114 2315
Optimistic	264 884 (23.4% of base[5])	(18%[9] 1st 5 yrs) (10%[8] 2nd 5 years)	975 953[10])	(10%[8])	1 571 792	(10%[8])	2 531 371

1. Capturable Market — The nonSMSA and/or rural market for new mobile systems based on their provision of new services or improved services at prices comparable to current service changes.
2. Base market total in 1980 estimated as 6 mobiles/system × 188,664 systems or 1,131,984 mobile units in nonSMSA counties. Base data taken from ECOsystems study final report "Non-Urban Mobile Radio Demand Forecast," 1982, prepared for NASA by ECOsystems International, Inc. as part of a market study on the rural mobile radio market, 1980 count of nonSMSA counties employed.
3. Estimated from 1978 SIRSA membership report from survey taken on membership — 23.4% of respondents required additional coverage with 21.6% rate of return on a membership of 11,773 of 41,266 licensees in the Special Industrial Radio Service — by assuming Special Industrial is representative of all licensees, SIRSA membership is representative of Special Industrial Licensees, and survey coverage biased toward unacceptable service (.216 × 11773 = 2543 returns, (.234)(2543)/11773 = .0505)
4. Industry estimate of proportion of market that employs community repeaters with the assumption that this proportion requires improved service.
5. See footnote 3. Estimated by assuming no bias in respondents to SIRSA Survey and in relationship of SIRSA membership to total Special Industrial licensees and by assuming Special Industrial is representative of all licensees.
6. Average annual growth rate.
7. This growth rate taken for comparative purposes. See Footnotes 8 and 9.
8. Projected annual growth rate for 1980-1990 taken from International Resource Development, Inc. 1980 Report No. 156 "Mobile Radio Markets."
9. Average annual growth rate for 1975-1980 from "1981 Electronic Market Data Book" prepared by the Market Services Department of the Electronic Industries Association.
10. We assume that the recent past market performance continues into the near future (5 years) and after that the market grows at a lower rate. See footnotes 8 and 9.

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Table 4

CAPTURABLE[1] MOBILE RADIO MARKET (MOBILE UNITS) MOBILE RADIO TELEPHONE SERVICE

Possible Base Market[2]		1990[6]	(AAGR[7])	1995	(AAGR[7])	2000
Conservative	Population of 10,316,401[3] (Counties with ⩽ 20 persons/square mile)	51 582	(5%[8])	65 833 (.64% of base[11])	(5%[8])	84 021 (.81% of base[11])
Likely	Population of 43,379,000[4] (Outside of towns > 1000 persons)	216 895	(7%[9])	304 206 (.70% of base[11])	(7%[9])	426 665 (.98% of base[11])
Optimistic	Population of 57,562,000[5] (NonSMSA counties)	287 810	(10%[10])	463 521 (.81% of base[11])	(7%[9])	650 112 (1.1% of base[11])

1. Capturable Market – The nonSMSA and/or rural market for new mobile systems based on their provision of new services or improved services at prices comparable to current service charges.

2. Base market populations assumed constant for study (cf. footnotes 4 and 5). Base year taken as 1975.

3. Compiled from County and City Data Book, 1977. Counts for estimated 1975 data.

4. Statistical Abstract of the United States, 1981, page 14. Count from 1970 census – however, counts essentially constant for 1950, 1960, and 1970 censuses.

5. County and City Data Book, 1977, page 901. Count for estimated 1975 data – however, the revised count for the 1980 census based on 1980 SMSA's is 57,115,182 (cf. Statistical Abstract of the United States, 1981, page 919).

6. A market penetration of .5% of the population is assumed by the year 1990. This is consistent with AT&T, Motorola, and Telocator studies (cf. AT&T filing, FCC Docket CC 79-318, August 4, 1980; Motorola filing, FCC Docket 79-318, August 4, 1980; and "CMRS: Cellular Mobile Radio Telecommunications Service-Update on an Emerging Technology," Lehman Brothers Kuhn Loeb Research, May 7, 1982) and with an independent market study being prepared for NASA by ECOsystems International, Inc. and Corporate Research and Development, General Electric Company.

7. Average annual growth rate.

8. Average annual telephone growth 1950-1979 taken from "Independent Telephone Industry in the United States," Telecommunications Journal, 1980, Vol. 47, page 392.

9. Average annual mobile telephone growth 1970-1979 taken from "Land Mobile Market Integration Study," Final Report NASA Contract NASW-2800, November 1, 1980, by ECOsystems International, Inc., page 24.

10. Increased average annual mobile telephone growth of recent years – see footnote 9, page 24 for references.

11. See explanation of footnote 6. These penetrations are for comparative purposes and indicate that the base market and growth assumptions give results that are consistent with the cited studies in footnote 6.

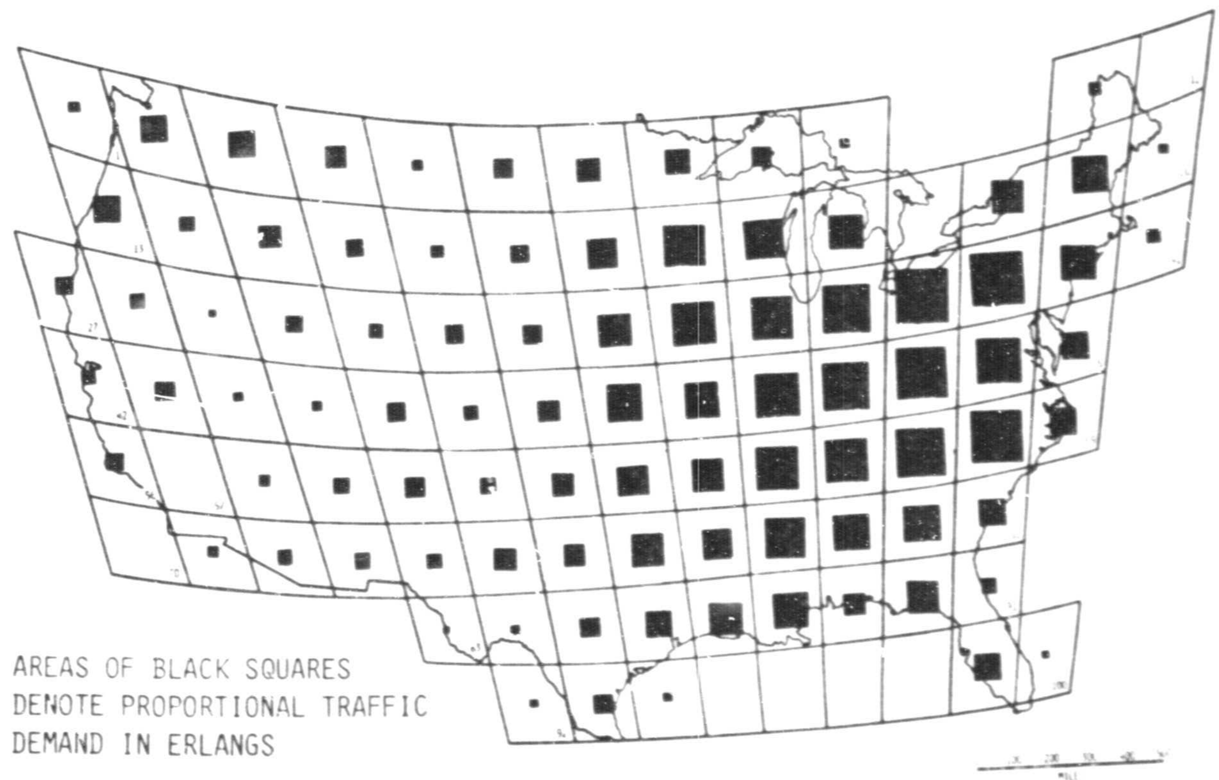

Figure 1. Demand distribution for mobile telephone in non-SMSA counties

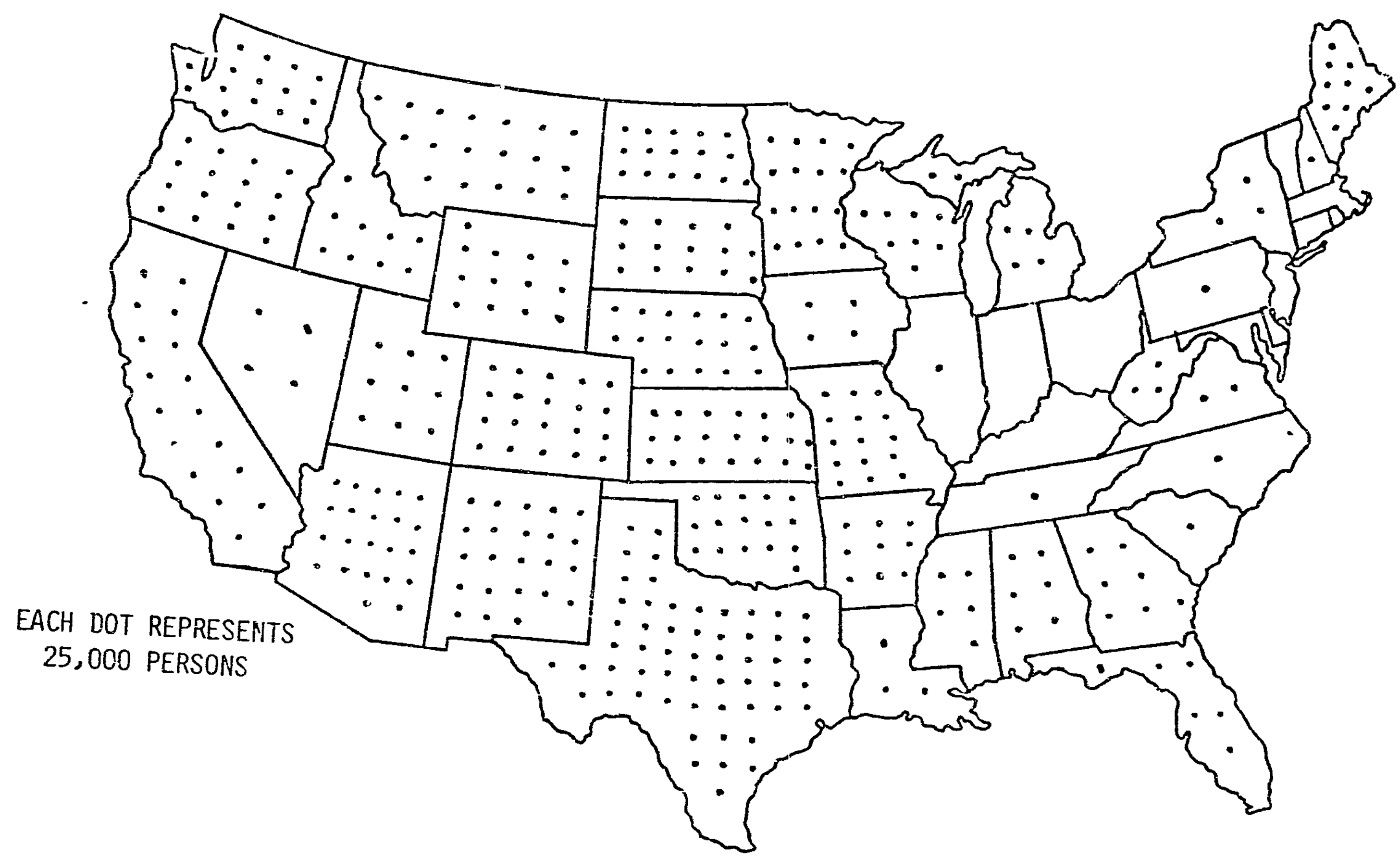

Figure 2. Distribution of counties with fewer than 20 persons per square mile

Distribution of radio traffic demand for intercity trucking was estimated on the basis of highway use of special fuels — primarily diesel fuels with small amounts of liquified petroleum gases. The use of such fuels reflects essentially all of the intercity long haul truck and bus traffic. Figure 3 shows the numbers of intercity trucks and trailers in each state for the year 1980.

The distribution of oil well services estimated demand is based on drilling activity. Table 4 lists by state the numbers of vehicles requiring voice communications and the numbers of data vans used for oil and gas well logging.

ELASTICITY OF DEMAND

Quality elasticity is defined as the additional price users are willing to pay in order to upgrade system performance from current to predetermined levels of improvement. A 1979 survey by the Special Industrial Radio Service Association (SIRSA) showed a general decline in satisfaction, with 6.6% fewer users (primarily metropolitan) willing to rate their system "excellent" in 1979 as compared to 1977. Comparison of business and special industrial user's base station costs with their willingness to pay a "premium for quality" shows that the user's willingness to pay is on the order of 7%.

DEMAND VS. COST

Potential business users of cellular mobile telephone systems in the Chicago metropolitan area were surveyed by Compucon, Inc. for Rogers Radio.[3] The following table presented with permission of Compucon shows respondents' interest in a mobile phase system at costs that include equipment lease but not long distance charges.

Level	$60	$120	$180	$240
Very Interested	9%	3%	4%	6%
Somewhat Interested	25%	22%	14%	15%
Not Very Interested	17%	18%	25%	21%
Not at all Interested	47%	56%	55%	56%
Don't Know (was not read as a choice)	3%	1%	2%	2%

A survey conducted by Opinion Research Corporation for General Electric was directed at households and thus reflects the private as well as the business and professional markets.

If the cost was $750 and the monthly service charge was $50.00, would you...?

Definitely purchase	0.6
Very likely purchase	0.9
Possibly purchase	4.4
Very likely not purchase	16.3
Definitely not purchase	76.2
Don't know/No opinion	1.5

The Opinion Research Corporation showed nearly equal interest in urban and non-urban areas.

[3] "A Cellular Radio Market Study for The Chicago Metropolitan Area," May, 1982, Prepared for Rogers Radio, Prepared by Compucon Inc., 13749 Neutron Road, Dallas, Texas 75234

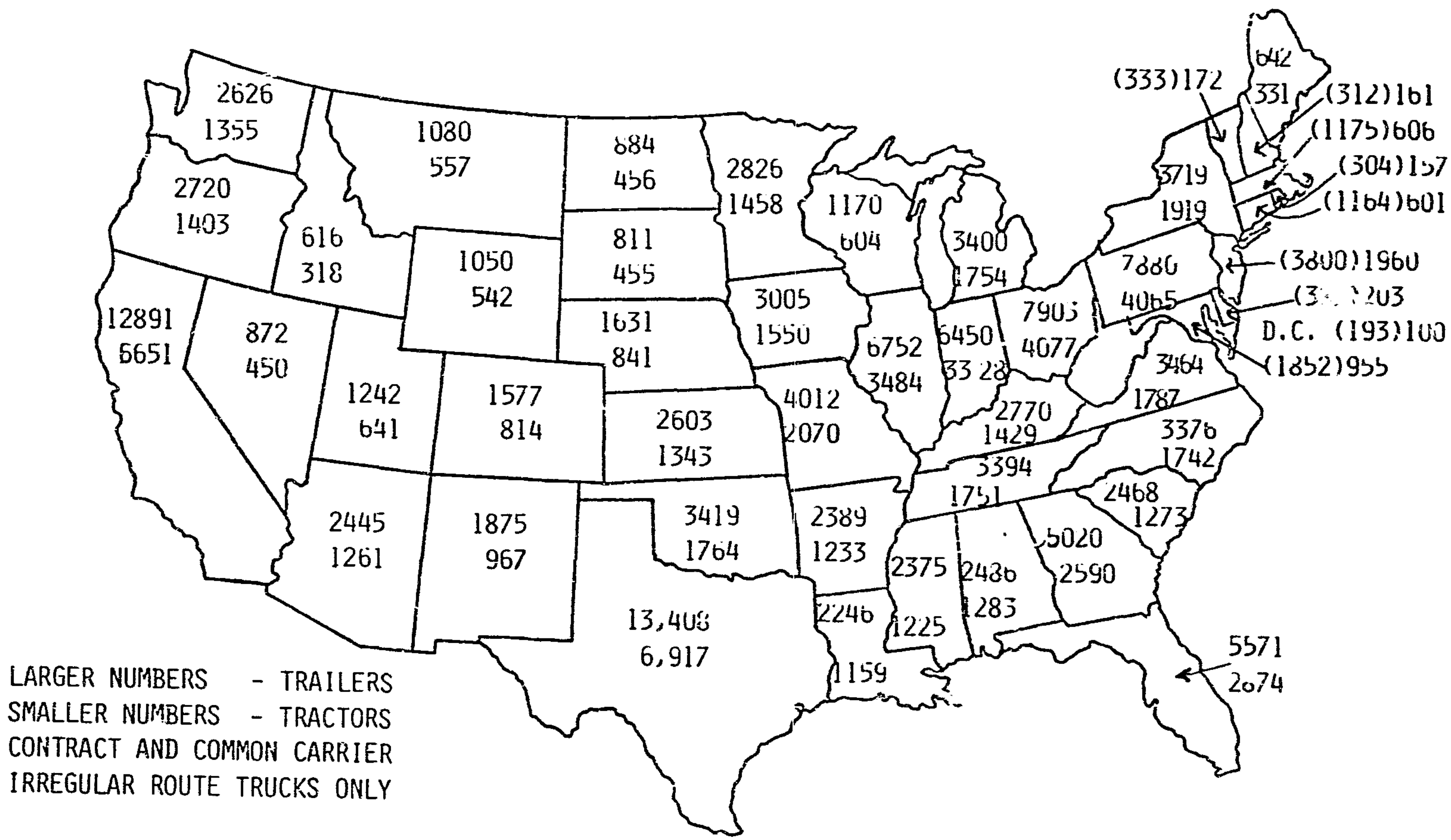

Figure 3. Distribution of truck traffic

DISTANCE DISTRIBUTION OF MOBILE RADIO TRAFFIC

Police mobile traffic range extends from a few kilometers up to a maximum distance subtended by the corresponding political boundaries. Maximum desired ranges are as follows:

Territorial Area (County or State)	Average Maximum Range (km)	Absolute Maximum Range (km)
Average Eastern County	20-30	40-60
Average Western County	50-70	100-140
Median State	150-200	300-400

Federal agencies require longer distance communications for applications such as law enforcement, illegal immigrant interdiction, and disaster control and relief. Radio communication with ranges of several hundred to more than 1000 miles is essential in some of the applications.

Analysis of a 1977 SIRSA report includes the required and achieved communication ranges of its members.

Industries in rural areas, such as petroleum, agricultural and mining services required longer ranges than industries in urban areas. "For example, 39.8% of those engaged in supplying services to the petroleum industry stated that they require a range of 51 to 75 miles and 15.4% stated that more than 75 miles was necessary.

When responses to a 1977 survey were tabulated by SIRSA staff, it was found that 23.4% of the returns noted that more communication coverage was needed than presently achieved.

CHANNEL CAPACITY REQUIREMENTS

Communication traffic is measured in erlangs. As used in the following assessment, an erlang is the traffic that will continuously occupy a voice bandwidth channel.

The channel capacity to handle the traffic is larger than the erlang demand because it must allow additional time on the channels for minimizing blocking of messages. If trunking is used, control channels are needed in addition to the talking channels.

A survey of 77 business and 32 special industrial users in randomly selected non-SMSA counties showed mean traffic generated by base stations is as follows:

Business	32.135 milli-erlangs
Special Industrial	25.004 milli-erlangs

An equal amount of traffic is generated by the mobiles in return; hence the total traffic is double the above. On the average, there are six mobiles per base station. For the purpose of estimating total traffic demand for dispatch services, we assume an average one-way demand of 0.028 erlangs per base station, or an average of 0.0093 erlangs of two-way demand per mobile. The values are the average demand generated during the normal working hours of the users.

The capturable market in the oil and gas well services industry is summarized from Table 1.

Mobile Units

	1990	1995	2000
Voice	35,736	41,428	48,626
Data	7,288	8,449	9,794

On the assumption that the average demand for voice communications in the oil and gas well services industry is 0.0093 erlangs per mobile, the peak demand in erlangs is:

Erlangs (Voice)

	1990	1995	2000
Erlangs	322	385	452

Based on the assumption that the increase in demand for data services will only follow the increase in the number of mobile service vans, the number of voice channel equivalent erlangs will be:

Erlangs (Data)

	1990	1995	2000
Erlangs	111	128.8	149.4

The capturable market for the trucking industry as described above is considered to be only the common and contract carriers on intercity irregular routes. Many other trucks may use a long range mobile radio service also, but the analysis is restricted to the portion of the industry whose representatives have expressed a definite need. The desired functions are position surveillance of trailers, automatic data transmission from trailers, and communications with drivers. The numbers of mobiles in the market segment are summarized from Table 2.

	Mobile Units		
	1990	1995	2000
Trailers	168,439	185,970	205,326
Tractors	86,900	95,945	105,931

Voice or voice equivalent (alphanumeric) communications with the drivers could replace the long distance wireline calls that are now used for dispatching trucks. The average dispatch traffic demand per vehicle, 0.093 erlangs, is assumed to apply to the trucking industry.

	Erlangs (Voice)		
	1990	1995	2000
Erlangs	808	892	985

The position fixing and low data rate communications will require short and infrequent messages from each trailer. A position fix can be accomplished in one second. Each status message will require only a fraction of a second transmission time at voice bandwidth rates. Guard time in the channels must be allowed because of the messages are transmitted at random times from the trailers. Messages are desired from many trailers when they are not attached to tractors because their status and load conditions are to be monitored. We assume five seconds of transmission per day from each trailer, or .00006 erlangs.

	Erlangs (Data)		
	1990	1995	2000
Erlangs	9.7	10.8	11.9

The attractiveness of the position surveillance and data transmission will depend upon the cost of the units for the trailers. The cost of the functions will be low because a very large number of units can be accommodated in one voice channel. If the equipment cost is low, a few hundreds of dollars, it is likely that a very much larger portion of the nation's four million trailers will use the service.

Commercial and public radio services use voice in the dispatch mode of communications almost exclusively. The capturable market is summarized from Table 3.

	Mobile Units		
	1990	1995	2000
Conservative	111,339	156,159	219,021
Likely	440,412	709,288	1,142,315
Optimistic	975,953	1,571,792	2,531,371

The predicted traffic demand in erlangs for commercial and public radio to satisfy non-urban needs for longer range and better coverage is:

	Erlangs		
	1990	1995	2000
Conservative	1,035	1,452	2,036
Likely	4,095	6,596	10,623
Optimistic	9,076	14,617	23,541

The FCC sampled some 50 common carriers widely distributed throughout the United States and determined that the average mobile radio telephone generates .014 erlangs of traffic. The number must be multiplied by two, since radio telephone service requires duplexing. The mobile traffic is thus .028 erlangs per subscriber. The capturable mobile radio telephone market is summarized from Table 4.

	Mobile Telephone Subscribers		
	1990	1995	2000
Conservative	51,582	65,833	84,021
Likely	216 895	304,206	426,655
Optimistic	287,810	463,521	650,112

Applying the estimate of .028 erlangs per subscriber to the above, the demand in erlangs is as follows:

	Erlangs		
	1990	1995	2000
Conservative	1,444	1,843	2,352
Likely	6,073	8,517	11,946
Optimistic	8,059	12,978	18,203

The sums of the traffic demands in erlangs are:

	1990	1995	2000
Conservative	3,730	4,712	5,986
Likely	11,419	16,530	24,168
Optimistic	18,387	29,012	43,342

Section 2

TERRESTRIAL SYSTEM CONCEPTS AND ANALYSES

PROCEDURES AND RESULTS

Terrestrial mobile radio systems concepts were generated and analyzed to determine how well they could fulfill the requirements for mobile radio services in non-urban areas of the United States up to the year 2000. The study assumed that terrestrial installations will serve the SMSA counties of the nation, but that terrestrial and satellite systems are both candidates for serving the less densely populated counties. As a basis for later comparison of the two candidates, an attempt was made to configure terrestrial systems that would meet the requirements defined in the previous sections. The systems concepts and analyses are limited to the non-SMSA counties of the United States. The non-SMSA area of the contiguous states is 2,386,391 square miles, or 80.5% of the land area. The non-SMSA population is 57 million persons, or approximately 25 percent of the total.

In the full report the results of the terrestrial systems study are presented as follows:*

- Present day mobile communications technologies, systems, and equipments are described including strengths and limitations. The material is presented as background for evaluating the concepts generated in the study.
- Average propagation ranges are calculated for terrestrial installations in each of seven physiographic areas of the contiguous states. The calculations are used to determine the number of installations required for ubiquitous coverage of all the non-SMSA counties. Consideration is limited to 800 MHz radios with cellular compatible characteristics.
- Four system concepts are defined and analyzed to determine how well terrestrial systems can fulfill the requirements at acceptable costs. The first system provides urban cellular-quality communications everywhere in the non-SMSA counties of the contiguous states. The second system provides ubiquitous coverage but without handover between cells. There are no means to place a call to a vehicle unless the caller knows in which cell the vehicle is located. The third system uses higher power cell site transmitters than the urban cellular systems, and remote receivers, spaced throughout the service area, to increase the service area of the cell. The remote receivers are connected to the cell site by telephone lines or microwave links. The fourth system uses the higher power cell site transmitters and power amplifiers on the vehicle transmitters to achieve the greater service area in the cell without the need for the remote receivers.

All of the systems operate in the 800 MHz band. There are two reasons for the choice. First, the allocation of channels and the techniques for using the lower frequency mobile bands do not provide a sufficient number of channels to accommodate the large demand. Second, compatibility with urban cellular systems is necessary to fulfill some of the requirements.

* In this Executive Summary they are presented in reverse order.

The 800 MHz band is the band of choice for the urban cellular systems because propagation range can be limited to short distances. A channel can be reused several times within the limited geographical area of a city. Range can be much shorter than the line-of-sight distance to the horizon.

The 800 MHz band is not the band of choice for non-urban systems because the propagation range is short and the signals are severely blocked by terrain features, structures, and foliage. The number of installations to serve an area is greater if the installations operate in the 800 MHz band than if they operate in a lower frequency band.

Signal propagation range at 800 MHz is strongly affected by terrain roughness. A map supplied by the U.S. Coast and Geodetic Survey outlines seven physiographic areas of the contiguous states. Sample topographic maps, believed to be representative of each physiographic area, were selected, and terrain roughness estimates were made and used to calculate propagation range in accordance with the accepted procedures of the mobile radio industry. Average service area of a terrestrial installation was determined for each physiographic area, for a typical base antenna height. The number of installations required for each area was calculated. The total number of installations for the non-SMSA counties of the contiguous states is 33,130 and for the entire contiguous states it is 40,098.

The first of the four system concepts provides full cellular capablility throughout the contiguous states. The 40,098 cells are arranged in 24 cell clusters, each cluster controlled by a Mobile Telephone Switching Office (MTSO). Equipment and installation costs were estimated for an average cluster, and the cost multiplied by the number of clusters. Total cost was $15.74 billion. The cost is so high that no further analysis of the system was made.

The second system eliminates the MTSOs. Each cell operates independently without handover between cells. Frequent redialing during calls is necessary as a vehicle moves from one cell into another. There is no means to place a call to a vehicle unless the caller knows which cell the vehicle is in. The cost of individual cells was based on a population density of 20 persons per square mile, an assumption that one percent of the population would be subscribers, and an average cell radius of six miles as determined by the propagation analysis. Total cost for the system was calculated to be $9.7 billion. Monthly recurring costs for the system are $177 million, and the base user cost, without profit, $502 per month.

The third system relaxes the cell site specifications. It uses higher transmitter power and greater freedom to choose transmitter sites than is permitted in urban cellular systems. An average 15 mile service range is assumed, based on experience with the General Electric GE MARC5 800 MHz trunking system. There are many shadowed areas that do not have service, but careful siting of the transmitter and receiver towers can optimize the coverage. Remote receivers throughout the service area enable the 4 watt mobile transmitters to be heard. The number of transmitter installations is reduced from the number required in the first two systems. Costs were determined for individual installations based on a population density of 20 persons per square mile and one percent of the population as subscribers. Implementation costs are $377,000 for the minimum capacity cell that serves 141 persons in its 675 square mile service area. Monthly recurring costs are $11,500 and the cost per subscriber is $142 per month.

The fourth system is like the third except that no remote receivers are used. Talkback from the mobile units is made possible by the addition of a 35 watt power amplifier to the cellular mobile radio. Implementation costs are $307,000 for the minimum capacity cell, monthly recurring costs are $9,250, and cost per subscriber is $106 per month plus $10 per month for the power amplifier.

The market penetration of 1% of the population is based on an average user charge of $100 per month. The elements that make up the charge comprise a base user charge of $30 per month and local calls charged at $0.27 per minute. Long distance charges are additional. Implementation costs and recurring costs must be recovered through the base user charge. The monthly subscriber costs stated above do not include profit, and therefore the base user charges must be higher than the stated costs.

It is obvious that none of the systems can serve a population density as low as 20 persons per square mile and return a profit to its investors. The fourth system was further analyzed to estimate the population density that would support the investment. At a population density of approximately 100 persons per square mile the total cost per subscriber is approximately $100 per month. Subscriber monthly costs do not scale linearly with population density because system capacity must be increased to accommodate the larger number of subscribers.

The third and fourth systems are like the present Improved Mobile Telephone System (IMTS) except that they operate in the 800 MHz band instead of the 150 or 450 MHz bands. More channels are available in the higher frequency band so that capacity is increased and call blocking is reduced. An important advantage is compatibility with urban cellular systems so that the cellular mobile equipments can be used, except that the fourth system requires the addition of a power amplifier.

Structures and terrain features cause sharper shadowing of the signals at 800 MHz than they do at 150 or 450 MHz. Foliage attenuation is greater at the higher frequency. Equivalent service is more costly at 800 MHz than at the lower frequencies.

The study of terrestrial systems did not uncover any ways to reduce the cost of terrestrial systems or improve performance so that a ubiquitous mobile radio service with a national architecture could be implemented and operated at a profit.

The normal development of terrestrial mobile radio systems will continue to serve specific needs of local areas as in the past. "Nationwide service" in terrestrial systems will be limited to compatibility between local areas. There is no economic incentive to provide service in thinly populated areas except for the specific needs of local entities who implement and operate their own facilities. There is no economically feasible terrestrial system approach that will provide nationwide services for users with needs such as those described as "New Services."

NUMBER OF INSTALLATIONS FOR A UBIQUITOUS MOBILE TELEPHONE SYSTEM

The feasibility of implementing a terrestrial mobile phone system depends largely on the number of fixed installations required to cover the intended service area. The range of each installation depends on the propagation impairments in the area.

Path blockage due to irregular terrain is an important factor in limiting range. The distance between fixed stations is thus a function of terrain roughness. A study was conducted to determine the roughness of the terrain in different physiographic areas of the United States, and thereby predict the typical range that could be expected in these areas.

The procedure to determine the range of an installation is as follows:

a) Specify the percentage of the area to be serviced; e.g., 95% (5% of desired service area is blocked by terrain).

b) Determine the terrain roughness from topographic maps; i.e., take 80% of the difference between maximum and minimum elevations along radials from the location of the installation. An example is shown in Figure 4.

c) Determine the height of the transmitter-receiver above the average terrain.

d) Specify the radio frequency, transmitter power, antenna gains and receiver sensitivity with appropriate fading margin.

e) Apply the graphs and formulas that relate the factors to range.

f) Compare the calculated results with results achieved in similar studies and installations.

The procedure was applied to sample areas taken from seven physiographic areas of the contiguous United States as defined by the U.S. Geological Survey (USGS). The result specifies the average range, hence the area served by a single installation in each of the physiographic areas. A USGS map delineates the physiographic areas (Figure 5). Dividing each physiographic area by the service area of a single installation yields the number of installations required in the area. Summing the numbers for all the physiographic areas yields the total number for all the contiguous states. Table 5 presents the results of the computation.

The average range is greatest where terrain is relatively flat. For the Atlantic Plains region of the southeastern United States, the average range is 20 miles. The Interior Plains region, including the Dakotas and the central plains southward to Texas, shows an average range of 10 miles.

The rugged Rocky Mountains are difficult to cover everywhere at 900 MHz, and the average dependable range is only 2 miles. Fortunately the percentage area of the country is small. The overall average range is about 5 miles, and increases to 6.5 miles if the Rocky Mountain System is excluded.

The total number of installations required to cover the contiguous United Stations completely is 40,098. Approximately half that number of installations is required to cover the Rocky Mountain System.

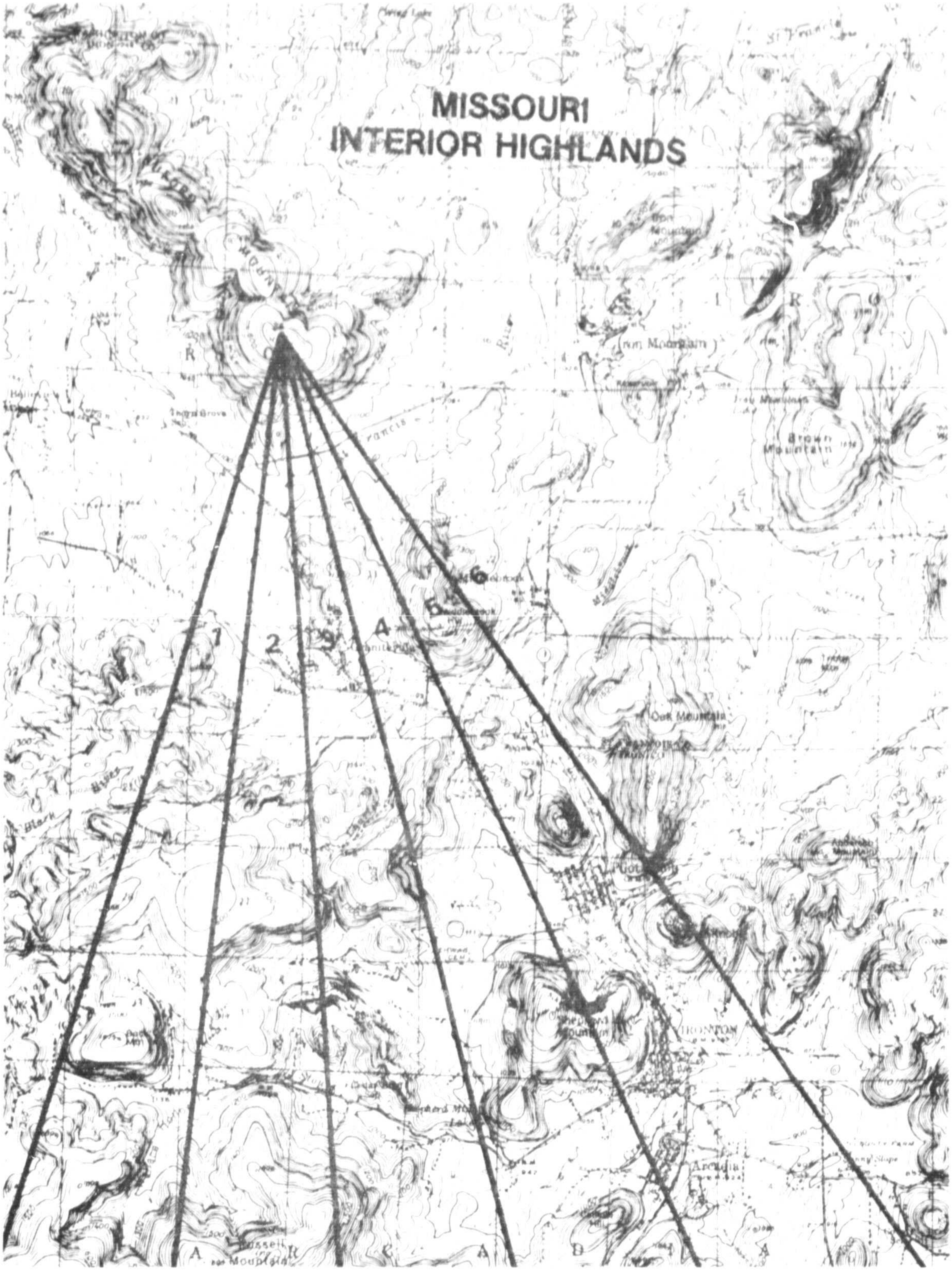

Figure 4. Sample topographic map

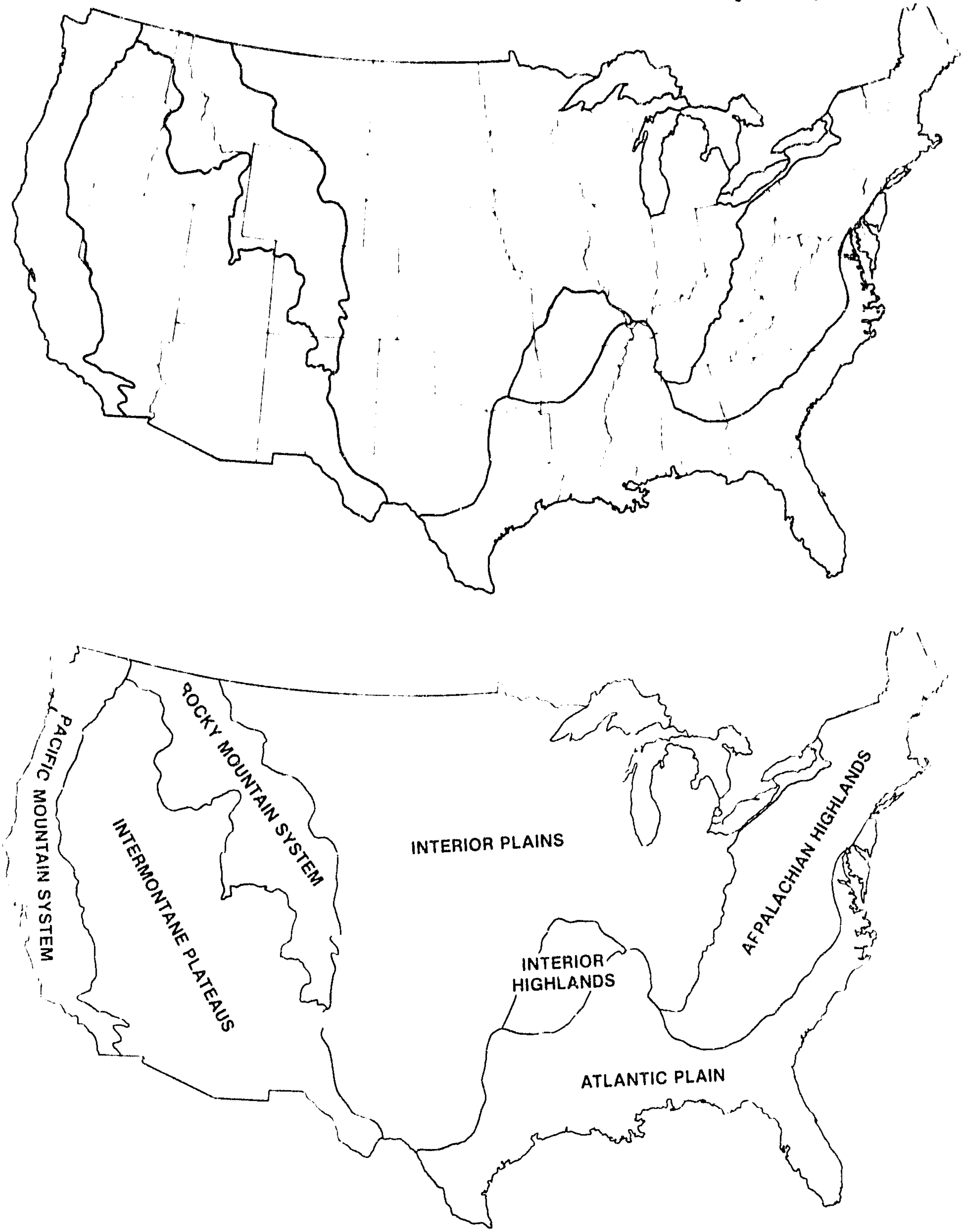

Figure 5. Physiographic areas of the United States

Table 5

CELLULAR COMPATIBLE TERRESTRIAL INSTALLATIONS FOR NATIONWIDE COVERAGE

Major Physiographic Divisions	% Of Country	Terrain Roughness Δh (m)	Maximum Plane Earth Loss (dB) For Min. Signal Mobile to Base	Range (Miles)	Installation Service Area (Sq. Miles)	Contiguous States Coverage Required Installations	Non-SMSA Coverage Required Installation
Atlantic Plains	14.9	7	141	20	1257	351	283
Appalachian Highlands	11.3	220	110	4	50	6,683	4,540
Interior Plains	38.5	70	126	10	314	3,605	3,084
Interior Highlands	1.9	144	118	6	113	504	428
Rocky Mountain System	8.6	544	95	2	13	19,459	17,971
Intermontaine Plateaus	20.0	143	118	6	113	5,208	4,320
Pacific Mountain System	5.7	267	108	3.5	38	4,340	2,504
					TOTAL	40,098	33,130

NOTE: The total area of the contiguous U.S. is 2.96 million square miles

Section 3

SATELLITE SYSTEMS CONCEPTS AND ANALYSIS

INTRODUCTION

A land mobile satellite system (LMSS) consists of three elements: a space system (comprising satellites and a Network Operating Center), mobiles, and gateways.

Figure 6 depicts the operating arrangement. The satellite operates as a simple frequency translator between the mobile band at UHF 806-890 MHz and the fixed-satellite service, presumed to be at S-band (2500-2690 MHz) or Ku Band (12/14 GHz). Ordinary communications are between the mobiles and gateways. Signalling, and the interactive data-surveillance links, are between the Network Operating Center (NOC) and mobiles and between the NOC and gateways.

A land mobile satellite system or LMSS provides communications services to mobile subscribers just as a terrestrial system does. However, there are substantial advantages to providing these by satellite, and these advantages are emphasized in the LMSS system architecture and system design.

Foremost is "ubiquity," the ability to provide services to the entire U.S. (and offshore), thus removing the line-of-sight limitations of a terrestrial link. Ubiquity applies to both the mobile link, between satellite and mobile, and the "fixed" link between satellite and gateway. The latter is as fundamental as the former, because the gateway, if properly located and of low enough cost, can bypass expensive long distance dial-up telephone lines. Almost as important is the satellite link performance. If a properly designed mobile antenna is used, multipath and noise effects are largely avoided. In addition satellite signals have nearly uniform signal density on the earth's surface, minimizing both co-channel and adjacent channel interference. Satellite links do not exhibit the Rayleigh fading characteristic of terrestrial links, and have large coherent bandwidth. Wideband data, such as 56 KBPS, are efficiently transmitted on satellite links. This is contrasted to terrestrial systems which are plagued by multipath and co-channel and adjacent channel interference.

An important advantage of LMSS is its national architecture. If a centralized network operations center (NOC) is used, then each satellite coverage "cell" is connected to it via its common signalling channel. This has several advantages. First each mobile can be automatically located within each beam by the NOC, and therefore the mobile can be paged (addressed) at any time. While possible in principle, terrestrial paging of wandering mobiles is difficult and expensive, and is not a planned service. A second advantage is the ability to establish mobile-NOC communications using packet-switching technology. In this situation the NOC can address the mobiles and achieve efficient two way transmission and surveillance (two-satellite ranging or position location). Without the intermediary of the NOC, contention access is required with resulting transmission inefficiencies.

LMSS also has disadvantages compared to terrestrial systems. The foremost of these is the inability to achieve the small cell (antenna foot print) size inherent in terrestrial systems. Terrestrial systems operate well with cells as small as a mile in radius. Thus terrestrial systems offer considerable frequency reuse in small areas — just what is needed to serve urban areas. LMSS may show a relatively greater advantage in non-urban areas. Together, terrestrial and satellite systems are complementary and provide an efficient, attractive total service.

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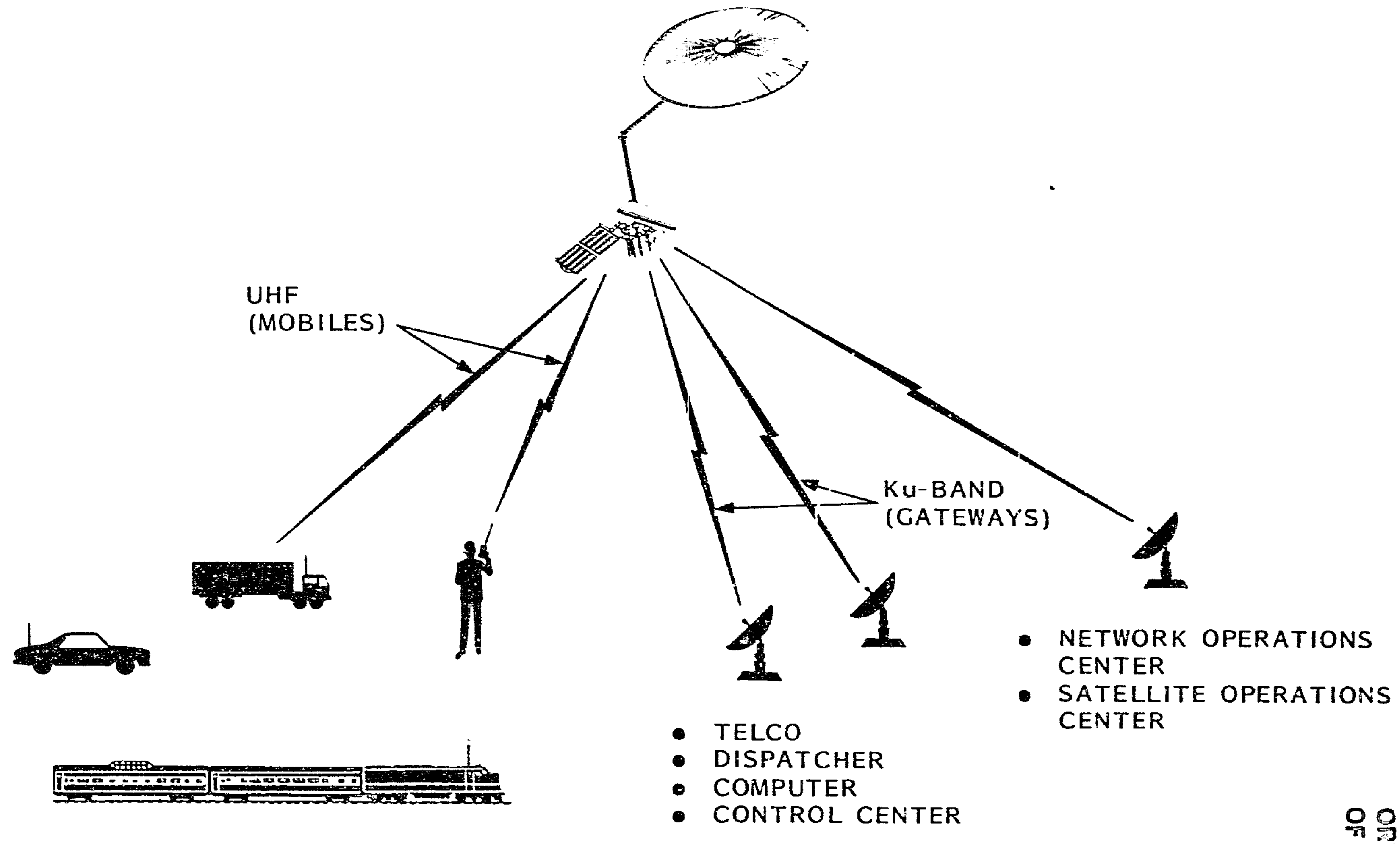

Figure 6. Land mobile satellite system operation

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LMSS also does not function well in urban areas because of building blockage, building multipath, and intense man-made noise.

Another disadvantage of LMSS is its large single investment and high-risk technology. An important role can be played by government, and particularly NASA, in order to help bring an LMSS into being.

SERVICES

Four generic services characterize LMSS. These are:

1. Cellular compatible radio telephone with dial-up voice or wideband data (mobile subscriber uses either terrestrial or satellite).
2. "Stand alone" radio telephone with dial-up voice or wideband data (mobile subscriber relies solely on LMSS). This service may include rural telephone.
3. Trunking or dispatch with dial-up voice or wideband data, or "push to talk" (communications are limited to one or a small number of gateways).
4. Interactive data/surveillance, (occasional bursty data and surveillance), which can include paging, an important terrestrial service.

The subscriber may be in a vehicle such as a car, truck, train, bus, in a boat on the intracoastal waterway system, or on foot.

SYSTEM ARCHITECTURE

The system architecture is best described by separating the three system elements -- the satellite system, gateway system, and mobiles. Figure 7 depicts the functions of these elements. In Figure 7a dial-up communications are depicted between a mobile and a gateway with the satellite functioning as a frequency translator and amplifier. Figure 7b illustrates signalling between the NOC and mobiles and between the NOC and gateways. In this arrangement the NOC maintains positive control over system operation. In the example, the satellite translates from UHF to S-Band (and reverse); consequently the gateway has UHF equipment for signalling and S-Band equipment for communicating. Other arrangements are possible. In Figure 7c the NOC terminates one end of a mobile-NOC link and one end of a gateway-NOC link for the interactive data and surveillance services.

Both compandored FM and compandored SSB-AM are considered. Objective performance is defined under idealized conditions (no obstruction, multipath, or man-made noise) requiring margins for fading. In the case of FM, CNR = 15 db, and fade to CNR = 10 db (perhaps to 8 db with an extended threshold) results in an acceptable signal — intelligible, relatively noise free because of quieting and compandor action and comparable to terrestrial mobile signals. This is a C/No of 56 db-Hz for a 15 kHz center to center spacing. Operating much below threshold results in a rapidly degenerating signal. In the case of compandored SSB-AM, CNR = 15 db which, with a 3.4 kHz baseband, results in a C/No of 50 db-Hz and 4 kHz center to center spacing. There is no threshold, and intelligibility is still adequate at CNR = 3 db. Both modulations are resistant to co-channel interference. Selection of modulation and mobile antenna type are important subscriber selections because of cost.

Space System

Several satellite conceptual designs of 1, 12, 31 and 100 beams were studied in order to establish a range in capacity. Each satellite concept is characterized by a transponder diagram, (an example in Figure 8 depicts a 12 beam UHF and single beam S-Band arrangement), frequency plan, an antenna beam plan and a weight and power summary. A listing of these is

- VOICE COMMUNICATIONS (AND WIDEBAND DATA)
- POCKET (DATA) COMMUNICATIONS
- TPL

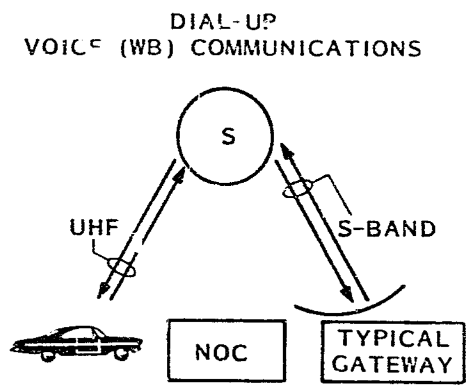

Figure 7a

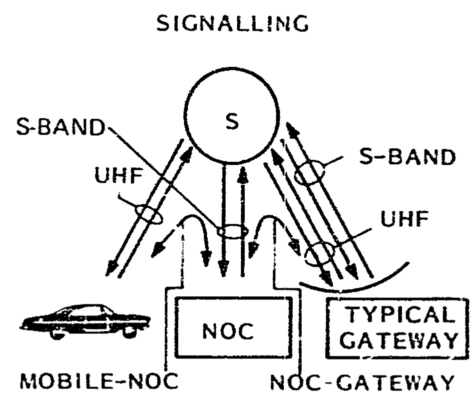

Figure 7b

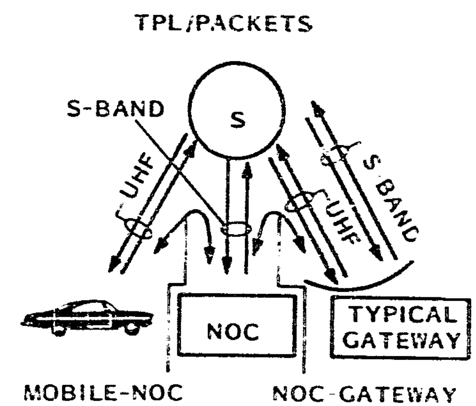

Figure 7c

Figure 7. Communications, signalling, and interactive links

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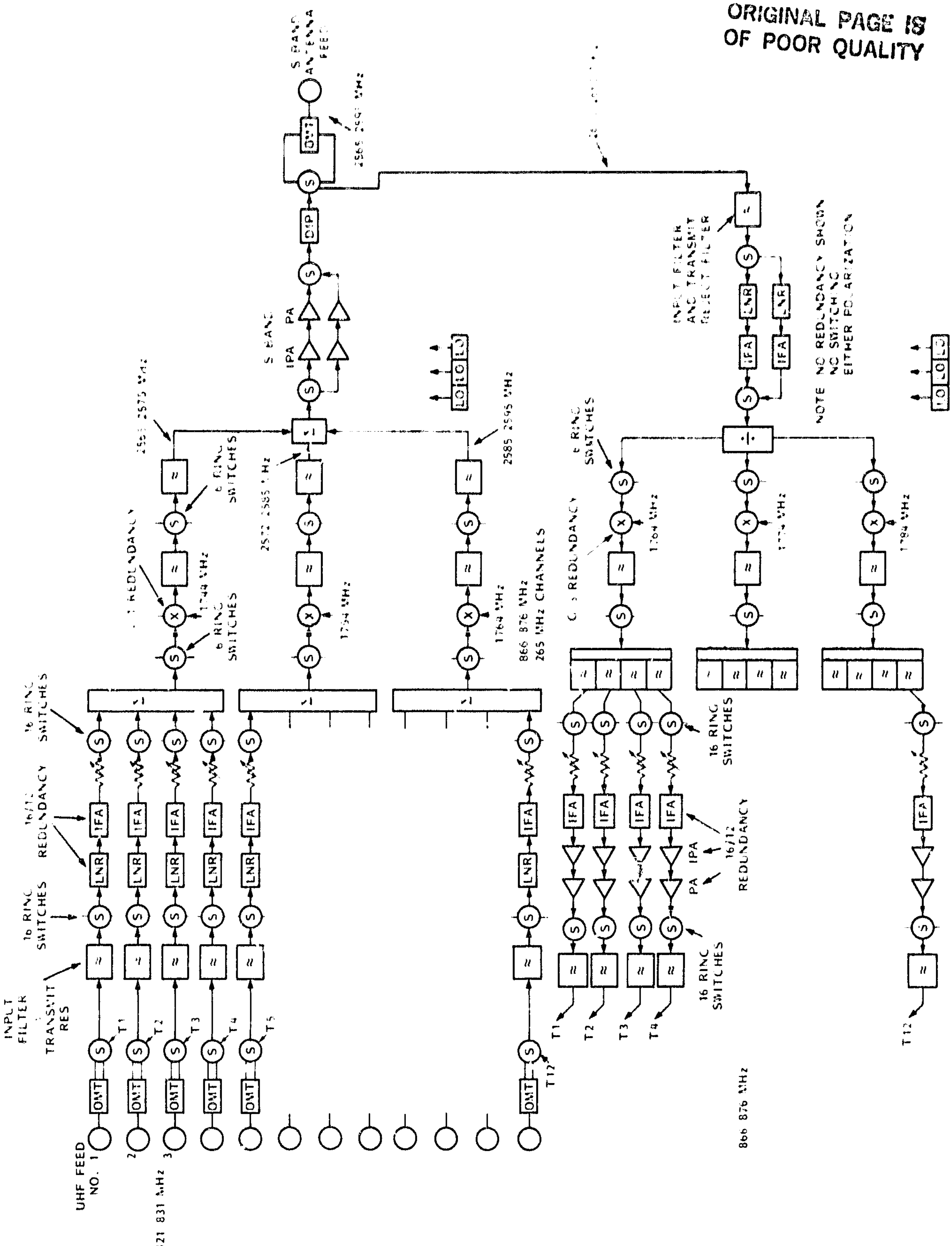

Figure 8. Concept B transponder concept

given in Figure 9. Each satellite transponder component was examined to identify salient characteristics, technology maturity and salient weight and power characteristics.

Some attempts were made to simplify the transponder arrangements to achieve minimum satellite weight and power. However, each of the design concepts, while not totally optimized or completely designed, is believed to be representative of the general industry technology base. Of course, the presence of the large UHF antenna, and the requirements for an offset feed to suppress interference, dominate the spacecraft configuration, deployment, and control. The satellite configuration is illustrated in Figure 10.

The basic system access format is FDMA, specifically single-channel-per-carrier or SCPC. In this system the satellites are not channelized, and circuits are provided by assigning complementary frequency sets to mobiles and gateways thus allowing conventional telephone signalling. The NOC is combined with the Satellite Operations Center or SOC in order to economize on certain equipment and on personnel and to make specific use of satellite position information for surveillance.

The NOC is conventional in design, with redundant computers, etc., in order to control the network and provide signalling and switching and other functions.

Gateways

The gateway terminal is a conventional single channel per carrier (SCPC) terminal. For radio telephone service it is located at a telephone exchange so that a call can be completed to the fixed end of the link. Low cost is essential to an economically attractive LMSS because it enables reasonable call minute charges for relatively small numbers of subscribers, thus allowing its location at a local exchange. Use of few large gateways requires virtually each call to be routed through the long distance dial-up network, which adds considerably to the total subscriber call-minute charge. A "single thread" design (without redundancy) favors low cost; temporary work-around during down times can be accomplished by a neighboring gateway and the telephone network. The single thread design, simplicity, standardization, and significant production quantities result in low cost. The gateway uses a 3 meter antenna, low power transmitter output amplifier, transistor low noise receiver preamplifier and SCPC modems, control and frequency synthesizer. Echo cancellers also are required.

For trunking or dispatch, the gateway is located at or on the headquarters building and no telephone lines are required.

Mobile Radios

The mobile radio equipment for LMSS is similar to terrestrial radios in most respects and is expected to have similar production costs. However, there are differences. The antenna is circularly polarized and has an "upward-looking" beam in order to suppress ground reflections and man-made noise.

The simplest antenna configuration is a "turnstile" (crossed-dipole) but with "bent" or drooping elements in order to maintain circularity over a wider field of view. When mounted on a "cup" or "choke" instead of a ground plane, the antenna is compact, rugged, inexpensive and convenient enough for carrying by a pedestrian. Gain is about 4 dBi. Higher gain electrically and mechanically steerable antennas also can be used. These antennas have the advantage of greater multipath and man-made noise suppression as well as higher gain.

With regard to radios the RF power level is comparable to terrestrial systems. The receiver has a low noise amplifier. A terrestrial cellular radio and the fixed antenna described above require a minimum modification and can be considered cellular-compatible. Other modifications will achieve higher antenna gain and reduce channel bandwidth, which reduces

CONFIGURATION	A	B	C	D	D
NUMBER OF UHF BEAMS	1	12	31	100	100
UHF BEAMWIDTH*	6° X 4°	1.5°	0.77°	0.41°	0.41°
NUMBER OF FIXED SERVICE BEAMS	1	1	1	14	1
ON-BOARD SWITCHING	NO	NO	NO	YES	NO
SYSTEM CAPACITY** (MHz) (DUAL POLARIZATION)	20	60	260	500	500
EQUIVALENT FM/SSB TRUNKS***	1333/5000	4000/15,000	10,333/38,750	33,333/125,000	33,333/125,000

*SEGMENTATION 4:1
**2 SATELLITES
***CFM IS 15kHz, CSSB IS 4 kHz

Figure 9. Satellite configuration summary

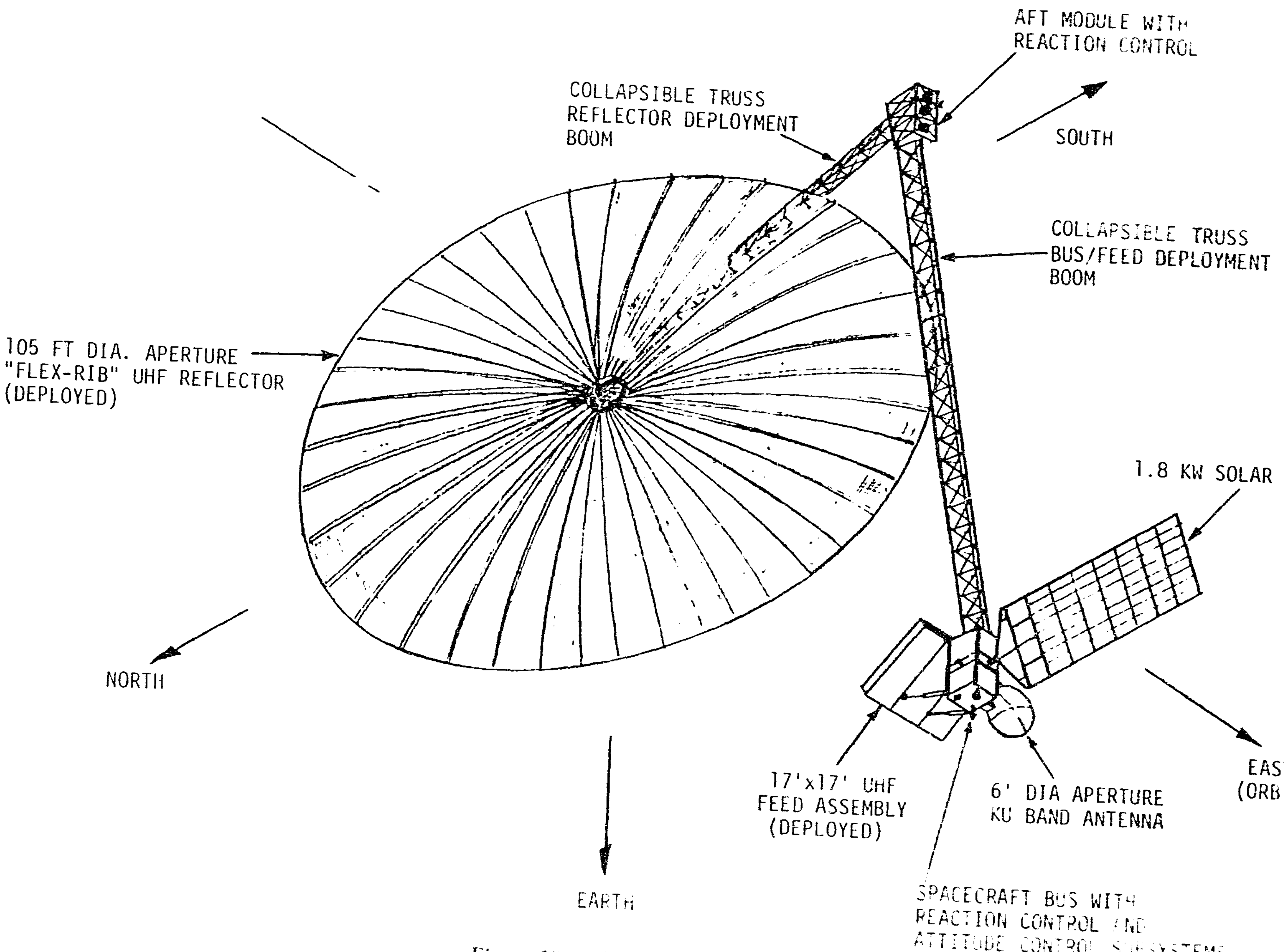

Figure 10. Orbital configuration

space system cost by increasing its capacity. If compandored single sideband amplitude modulation (SSB-AM) is used, better frequency stability is required, and can be achieved by locking the receiver to the satellite's common signalling channel carrier. The same carrier also can be used as a reference signal level, for automatic gain control (AGC), and for antenna steering if needed. These additions enhance both network and subscriber equipment performance with some increase in radio cost. The ever available common signalling channel enhances network monitoring and control. Individual subscribers or subscriber networks will choose the equipment arrangements most suitable — essentially balancing radio, satellite and gateway costs for maximum advantage.

An important final radio type is a simple, low-cost, fixed tuned transceiver for operating with the NOC using a packet switched protocol. Intended for non-voice service with low average but bursty throughput, the transceiver is key to a command, telemetry and surveillance network. In normal operation the NOC interrogates these units one by one by use of a discrete address and assembles the return data for distribution. Periodic pauses in the interrogation (via an "arming" code) permit "spontaneous" alarms to be sent by those units in the alarm state. Also specific units can be commanded to provide control functions or instructional read-outs, and specific units can be commanded into a "turn-around mode" so that ranging through two satellites can be accomplished in order to locate the unit to within 0.2 miles. Many applications in transportation and government are anticipated. This transceiver has no counterpart today in terrestrial systems. A simple receive-only unit, similar to existing terrestrial pagers, permits paging by satellite.

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COST ANALYSES

The space segment, gateway and mobile radios are costed separately. Because of the large number of parameters, system choices and market uncertainties, a parametric costing method was chosen which also helps to clarify the cost implications of these selections.

Space System

Investment in space systems was computed using the SAMSO model (June, 1981) with the model's technology indices and complexity factors adjusted to represent the mobile satellite design. The five spacecraft models, each at three different power levels, were used to compute the non-recurring and recurring costs. Launch vehicle and launching costs and insurance costs and NOC/SOC costs were added, and a system investment consisting of three satellites and two launches was developed for the 15 models. This enables space segment investment vs. spacecraft weight and power and capacity to be developed. Space segment investment versus number of equivalent 4 kHz circuits is given in Figure 11.

Similarly, a gateway equipment list was developed and costed by analogous costing methods. The transmitter output power amplifier (HPA) cost was developed parametrically since this is a function of satellite capacity, gateway capacity and modulation. Alternative connecting methods such as radio relay, leased lines, dial-up lines, etc., from a distant gateway also were examined and compared.

Costs for mobile radios were estimated analogously by comparison to estimated prices of cellular equipment. Productization and high production were identified as keys to low cost. Since the satellite compatible mobiles are similar to terrestrial mobiles, similar, but somewhat higher prices are expected. However, a considerable range in prices is expected because of the many subscriber choices available, e.g., SSB vs. FM, steered or non-steered antennas, etc.

Subscriber Charges

The satellite investment is converted to an annual charge by assuming a 7 year life, complete payback, 20% or 40% return on investment, expenses, a tax rate of 46% with linear depreciation and zero salvage. Satellite "fill" also is considered. The gateway investment is depreciated over 10 years with a 10% interest rate plus 10% return on investment (20% total) with a 5% factor added for maintenance. The mobile radio, where applicable, is treated the same way except only 10% interest is included.

All costs are in the form of costs per unit time. Knowing expected, typical uses for radiotelephone and trunking/dispatch services, the cost per used minute, and monthly costs, can be computed. These are typical subscriber charges which defray all investments and expenses.

Typical subscriber charges are computed for satellite systems satisfying the "conservative," "likely," and "optimistic" market projections. Typical results are described for a system existing from the years 1993 to 2000, satisfying the "likely" market projection, e.g., a requirement for a satellite system having 80,000 equivalent 4 kHz circuits and 71 beams. Total space investment is 1470 millions of 1982 dollars.

The investment per circuit and investment per available 4 kHz circuit are depicted in Table 6 for typical subscribers (33 subscribers per trunk for radio telephone, 100 subscribers per trunk for trunking/dispatch). Narrowband subscriber investments are considerably reduced because of the larger number of 4 kHz circuits per satellite.

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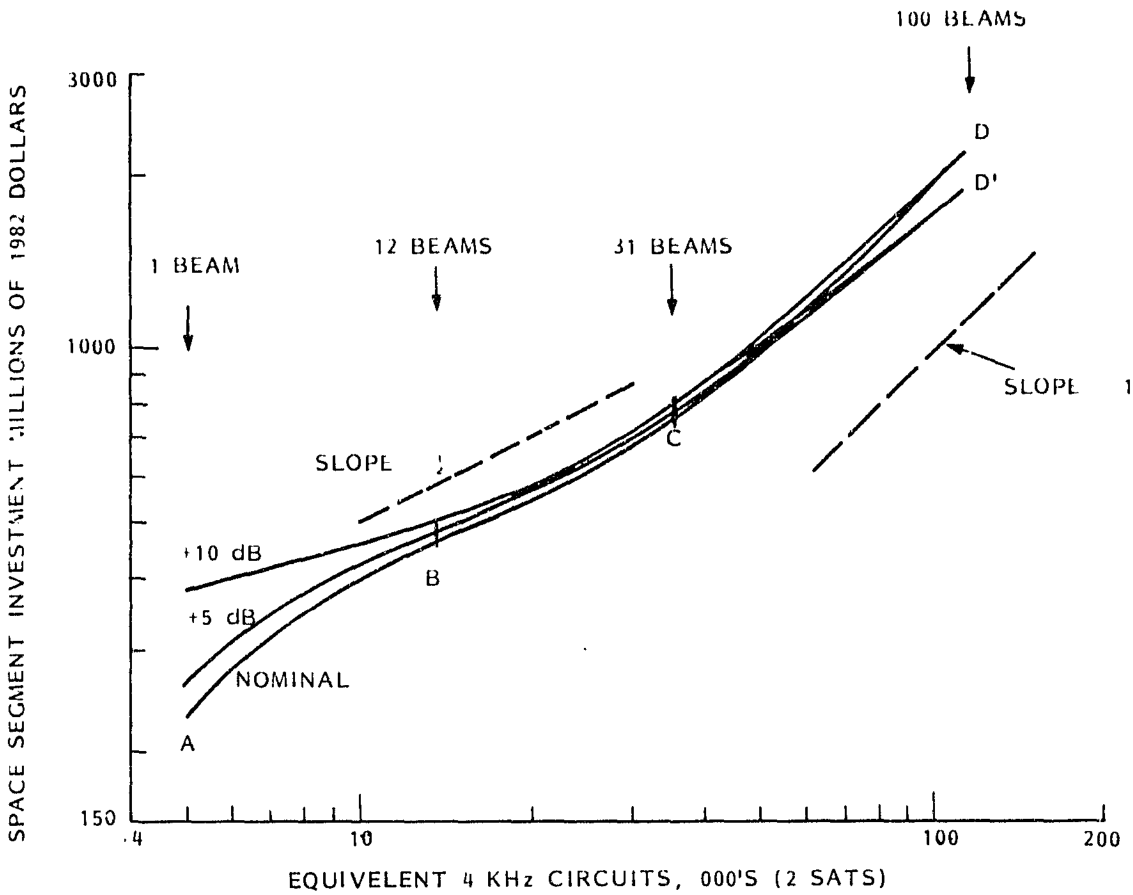

Figure 11. Space segment investment versus equivalent 4 kHz circuits for various UHF satellite powers

Table 6. Investment Per Trunk and Investment Per Subscriber, Total Investment = $1470M

TRUNK TYPE	SERVICE	INVESTMENT PER TRUNK	INVESTMENT PER SUBSCRIBER *
30 kHz	RADIO TELEPHONE	$ 137,800	$ 4546
15 kHz	RADIO TELEPHONE	$ 69,000	$ 2273
4 kHz	RADIO TELEPHONE	$ 18,375	$ 606
4 kHz	TRUNKING	$ 18,375	$ 184

* RADIO TELEPHONE = 0.03 ERLANGS PEAK, TRUNKING = 0.01 ERLANGS PEAK

Space segment call-minute charges are displayed in Table 7 as a function of service bandwidth and return on investment. The "asymptotic" value is obtained if the satellite is fully loaded with the prescribed service for 7 years. The "likely" case assumes the traffic growth of the "likely" market projections. The call minute charges for 4 kHz are especially attractive; however, all charges are attractive when it is realized that the subscriber can be located anywhere in the U.S. The larger call minute charge for 30 kHz bandwidth is simply the result of fewer circuits per unit bandwidth.

These charges can be converted to monthly charges by considering a typical call rate for a radiotelephone subscriber to be .03 erlangs in the busy hour, and for a dispatch subscriber to be .01 erlangs in the busy hour. Results are given in Table 8 for 20% and 40% return on investment and for the three generic voice services:

- 4 kHz dispatch
- 4 kHz (stand alone) radio telephone
- 15 kHz or 30 kHz cellular compatible radio telephone

These services are predicted to be dominant satellite services. Use of 15 kHz or 30 kHz for radiotelephone shows the sensitivity of cost to bandwidth; however, 15 kHz (and 20% ROI) results in costs that are comparable to cellular radio telephone. The other cases show the satellite monthly charges to be higher. This is a manifestation of the higher call-minute charge for the larger bandwidths. Again, this seems to imply that terrestrial cellular systems will be lower in cost and hence preferred when the subscriber is in range of the terrestrial cellular systems. The satellite will be used if he is a roamer, needs to be paged when he is outside his home district, or has a need for wideband data transmission. Therefore, cellular compatibility is needed, it results in an attractive service, and it makes possible a national radiotelephone architecture. The terrestrial satellite price structure emphasizes the complementary nature of the two services, e.g., cellular is best for short range, local communications requiring concentrated high capacity, and the satellite is best nearly everywhere else. A corollary is the lower performance expected of satellites in high rise urban areas due to shadowing, building multi-path and man-made noise. Both cost and performance considerations argue for both technologies if a truly national mobile radio telephone service is to be available to everyone.

Monthly charges for trunking subscribers are very attractive, particularly when it is realized that these are *independent* of distance from the dispatcher or headquarters, and no additional telephone lines are required. If the system requires long distance communications such as in transportation, there is simply no alternative to satellites which avoids the expensive overland TELCO charge.

Gateway installed costs are approximately in the range of $50,000 to $100,000 depending on gateway capacity, satellite antenna gain, number of production units, etc. This cost can be annualized as described previously and distributed according to usage. Results are given in Table 9 in terms of call-minute charges in cents per minute versus gateway busy hour traffic in erlangs, assuming a 2:1 peak to average factor. Charges in the range of 1 erlang are attractively low and reasonable compared to the space segment. If traffic is very light, below 0.1 erlang, gateway charges increase substantially and alternative means, such as distribution via the TELCO from a neighboring gateway, might be more desirable.

The sum of space system and gateway charge is the total system charge to be compared with terrestrial systems. For radio telephone, it is assumed that the fixed end of the link, e.g., the land telephone, is within the local exchange of the gateway. If this is true, no additional TELCO charges apply, even if the mobile is 2000 miles away. If the land telephone is

Table 7. Call Minute Charges for Space Segment

TRUNK TYPE	RETURN ON INVESTMENT = 20%		RETURN ON INVESTMENT = 40%	
	CHARGE FOR LIKELY MARKET PROJECTION	ASYMPTOTIC VALUE	CHARGE FOR LIKELY MARKET PROJECTION	ASYMPTOTIC VALUE
4 kHz	5.3 ¢/MIN	3.2	9.6	5.6
15 kHz	19.6 ¢/MIN	12.0	35.7	20.7
30 kHz	43.2 ¢/MIN	26.4	78.7	45.7

Table 8. Space Segment Monthly Charges for Typical Subscribers

TRUNK TYPE	SERVICE	RETURN ON INVESTMENT = 20 %	RETURN ON INVESTMENT = 40 %
4 kHz	TRUNKING	$ 11.60	$ 21.00
4 kHz	RADIO TELEPHONE (STAND-ALONE)	$ 29.93	$ 54.18
15 kHz	RADIO TELEPHONE (COMPATIBLE)	$ 128.70	$ 234.45
30 kHz	RADIO TELEPHONE (COMPATIBLE)	$ 283.70	$ 516.80

Table 9. Typical Gateway Charges

GATEWAY TRAFFIC ERLANGS	CALL-MINUTE CHARGE CENTS PER MINUTE
0.1	17
0.5	5
1.0	2
1.5	0.9

Table 10. Equivalent Transceiver Charges

	INSTALLED COST	MONTHLY CHARGE	MINUTE CHARGE
RADIO TELEPHONE	$ 1500	$ 26	4 CENTS
TRUNKING	$ 1000	$ 18	8 CENTS
INTERACTIVE DATA	$ 100	$ 2	8 CENTS

Table 11. Typical Total Subscriber Charges (Space Segment, Gateway and Mobile Radio)

TRUNK TYPE	SERVICE	MONTHLY CHARGE DOLLARS	MINUTE CHARGE CENTS
4 kHz	TRUNKING	34	15.3
4 kHz	RADIO TELEPHONE	69	11.3
15 kHz	RADIO TELEPHONE	168	25.6
30 kHz	RADIO TELEPHONE	323	49.2

not within the local exchange area, then additional telephone charges may apply. For dispatch systems the gateway is at the system headquarters, and in general no TELCO charge applies. Finally, subscriber radio costs are tabulated in Table 10, in terms of monthly charges based on 10% interest, 10 year payback and 5% maintenance. All three charges — space, gateway and mobile radio — can be added together to obtain total typical charges for the LMSS service. These charges are given in Table 11 for the case of 20% return on investment and a gateway peak capacity of one erlang.

Since typical short distance telephone rates are approximately 50 cents a minute the avoidance of these charges is a key to satellite system economic viability. Use of only a few gateways means that almost every call involves a TELCO charge, greatly increasing system cost. Consequently the system recommended for LMSS involves thousands of gateways, each operated by the local RCC or WCC, and located by a telephone exchange or operated by a private government or industrial (SMR) user.

The interactive, packet switched system for control, telemetry and surveillance also is estimated as an example in Table 10. Actually the charge for this service is probably dominated solely by the radio costs. For example a 250 bit register read out five times a day at a 6 KBPS channel data rate results in a miniscule activity factor. The number of users, N, that can be accommodated is:

$$N = \left(\frac{6000 \times 60 \times 60 \times 24}{250 \times 5} \right) Z = 414{,}720Z$$

where Z is a factor accounting for overhead, idle time, peak factor, etc. Tens of thousands of users, perhaps more, might share a single data channel (which is an equivalent voice channel). Satellite system charges, therefore, are not significant. If the gateway already is used for voice and wideband data, its cost also is not significant. It is believed that the only significant charge for this service will be for the radio and for the data processing.

The technology of the satellite also was examined briefly. The deployment and pointing of a large multiple beam antenna from a geosynchronous satellite is beyond the current state of the art and requires extensive development. The offset fed antenna, required to reduce sidelobe levels, results in a "distributed" spacecraft with difficult thermal control problems. The modular transponder electronics can benefit from LSI/MIC techniques; a different approach to diplexing and channelization filters is required to reduce the weight of these components.

RESULTS

1. Dispatch (SMR) services including voice, wideband data, control, telemetry and surveillance and paging are attractively priced and are insensitive to distance.
2. Radiotelephone by satellite, using narrow bandwidth modulation, is attractively priced, ubiquitous except in local high rise areas, provides high performance and is insensitive to distance. Cellular compatible radio telephone using FM adds ubiquity to the terrestrial service, and adds low cost long distance rates, wideband data and paging to the backbone terrestrial cellular system.
3. A satellite system can not provide the capacity to serve the dense populations in the urban areas of the nation; this can only be provided by terrestrial cellular systems.
4. A multiplicity of low cost gateways is a key to achieving low cost and flexible operation.

5. Narrowband modulation such as compandored SSB-AM is important to achieving attractive space system costs.

6. While not analyzed in depth, high gain steered antennas are believed to be important in suppressing multipath and man-made noise.

7. LMSS is cost effective despite the very large investments required. A mature system appears to require approximately one billion 1982 dollars of investment.

8. The technology of the large satellite is not yet established and requires additional development. This suggests that NASA can play a major role in the development of a multiple beam LMSS in the public interest so that the public will benefit from the early introduction of services.

Section 4

REGULATORY AND INSTITUTIONAL ASPECTS

Terrestrial systems do not require any regulatory or institutional changes. At the time of this writing the regulatory aspects of satellite systems are dominated by the problem of frequency allocation. The World Administrative Radio Conference in 1979 (WARC 79) authorized the frequency band 806-890 MHz for land mobile satellites. Within the United States the band is allocated for terrestrial land mobile. The Federal Communications Commission has studied the needs for present types of land mobile services and determined that by 1990 there will be a shortage of available land mobile capacity for present types of services in 19 major geographic areas and by 2000 there will be a shortage in 21 major areas.[4] The Commission is therefore very reluctant to introduce satellites into that frequency band, viewing satellite land mobile as a new service, and one that uses the spectrum less efficiently than other land mobile services. The proposed introduction of satellites into the band has alarmed many present service and equipment suppliers who have expressed their alarm in strong terms to the FCC.

Satellite land mobile is not generally opposed in principle by FCC or the industry. The important issues — the need for land mobile services that satellites can fill, and the business opportunities that they offer tend to be clouded by the concern over their introduction into the 800-900 MHz frequency band.

The use of the 806-890 MHz band was assumed in the study because it is the band allocated by WARC 79 and because it makes possible the implementation of a ubiquitous mobile radio telephone system through compatibility with the urban cellular mobile radio telephone systems. However some of the satellite applications do not require compatibility with terrestrial systems, and their technical requirements can be met at frequencies above 890 MHz. Other frequency bands should be considered for the service if there is a consensus that the service cannot be accommodated in the 806-890 MHz band.

The development of space technology has introduced a means of providing mobile radio services and functions that are new and important. The study that led to this report has identified needs for satellites in mobile radio services, and determined that large numbers of users can benefit from properly designed space systems. From a purely technical point of view, there is a wide choice of spectrum that is suitable for satellite land mobile, and the favorable propagation characteristics make it possible to communicate with narrower channel bandwidths than are used in terrestrial systems. Valuable services can be provided by satellite within a comparatively narrow spectrum allocation with considerable freedom to choose the portion of the spectrum in which the allocation is made. Other considerations, such as compatibility with other mobile systems should be taken into account in selecting the band. The important opportunity offered by space technology deserves serious consideration by regulatory agencies.

[4] Future Private Land Mobile Telecommunications Requirements, Interim Report, August 1982, Prepared by: Planning Staff, Private Radio Bureau, Federal Communications Commission.