DIRECT SATELLITE COMMUNICATIONS

FINAL REPORT

by

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EXECUTIVE SUMMARY

Mobile satellite service (MSS), a new technology designed to serve rural and remote areas, appears to have great potential for Alaska. Expected to be operational in a few years, MSS will allow the use of small mobile and transportable stations located virtually anywhere in the state.

Use of the new technology by state agencies has been examined, and six candidate applications have been identified. These applications, and the corresponding agencies, are:

- Highway communication - voice
  - Department of Public Safety
  - Department of Transportation and Public Facilities
  - Emergency Medical Services - state and local government
- Remote communication - voice
  - Department of Fish and Game
  - Department of Natural Resources
- Remote communication - low speed data
  - Department of Natural Resources
- Marine Highway communication - voice
  - Department of Transportation and Public Facilities
- Marine Highway communication - data
  - Department of Transportation and Public Facilities
- Emergency Services communication - voice
  - Department of Military and Veterans Affairs

Mobile satellite service can be provided to Alaska using presently available technology. Although mobile and transportable antennas operating in the state will use low radiation angles, terrain shadowing is not expected to be a serious problem. (Exceptions are the Dalton Highway and the Seward Highway.) The major impediment to the implementation of MSS is the Federal Communications Commission's slowness in making certain key decisions.

Cost estimates have been performed for the four candidate applications which involve voice communications. MSS may be less costly

than existing systems for one of the four applications, voice communication along the highways. Even for this application, MSS will be cheaper only if its ultimate costs are in the lower part of the presently anticipated range.

The real appeal of MSS, however, is not in the area of cost -- it is in reliability and convenience. There is no present day system which will allow one to move into a remote area and establish a reliable voice communication link within just a few minutes. It is this capability that offers dramatic potential for remote area and emergency communications. MSS also promises the most reliable voice and data communications for the Alaska Marine Highway.

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INTRODUCTION

Dramatic technological developments are expected to make mobile satellite service (MSS) available within a few years. This new service, which appears to have great potential for Alaska, will make it possible to communicate with radios which are installed in vehicles (mobiles) or radios that can be carried in backpacks (transportables) virtually anywhere on the continent. It is anticipated that the impact on communication services in rural and remote areas will be substantial.

The Federal Communications Commission (FCC) recently moved one step closer to making MSS a reality. The Commission is considering rules which would authorize the new technology, which could be in service as early as 1990. Before an operational system can be implemented, however, the FCC must allocate the necessary frequencies and license a system operator.

The National Aeronautics and Space Administration (NASA) has been working for some years to foster the development of MSS, and the Canadian government has been similarly interested. Twelve companies want to provide mobile satellite service in the United States. Canada is making plans to initiate its own service, and U.S.-Canadian cooperation is seen as a strong possibility.

Direct satellite-to-mobile service will be made possible by one or more satellites in geosynchronous orbit operating in the 800 MHz and 1.5 GHz bands with high effective radiated power. Narrowband, power efficient modulation techniques will be needed. Mobile units will need low noise receiver front ends and antennas with modest gain. Other ground stations, fixed or transportable, will be able to use the system if they have the same attributes.

The new technology should perform best in nonurban areas, where there will be few path obstructions. In urban areas, where buildings can cause path blockage and multipath problems, performance will not be as good. Mobile satellite service is seen as a way to dramatically improve many communication services outside metropolitan areas, filling the gaps left by present terrestrial systems.

CANDIDATE APPLICATIONS

Based on interviews with state personnel, a number of very promising applications of MSS by state agencies have been identified. These can be divided into three categories: communication with vehicles on the highway system, communication with remote locations, and other communications.

Vehicles on the Highway System

The Department of Public Safety and the Department of Transportation and Public Facilities (DOT&PF) both have major needs for communication with vehicles operating on the highway system, the former to support the Alaska State Troopers and the latter to support highway construction and maintenance operations. In addition, ambulances, which are not state vehicles, also have a critical need for such communication. Two-way voice communication with a dispatcher is needed in all cases. In addition to the above vehicular needs, it would be helpful for project engineers on DOT&PF construction sites to have telephones. Further, MSS will make possible emergency roadside telephones in remote areas.

A two-way voice communication system is presently operated by the Department of Administration's Division of Telecommunications Operations. This system uses VHF radio, in conjunction with a microwave relay system, to provide highway coverage. Although most areas of the highway system presently have adequate coverage, significant gaps exist along the Dalton, Richardson, Steese, Alaska and Edgerton highways.

It is possible that MSS can be used to fill in some of the existing gaps in coverage. It is also possible that, in the future, MSS will provide a more cost-effective and/or reliable communications system than the one presently being used.

Remote Locations

The Department of Fish and Game and the Department of Natural Resources both have significant requirements for communication with field personnel in remote locations.

Fish and Game operates about 100 temporary camps each year. These are staffed by biologists and other field personnel. The camps are operated in connection with fish counting and other management and research activities. Fish and Game also operates a number of vessels in conjunction with the same activities. All of these require two-way voice communication. The availability of telephone service would also be desirable in many situations. No present data communication requirement has been identified, but this may be needed in the future in connection with data entry and data access.

Two-way voice communication services are presently provided to remote Fish and Game personnel through the use of a variety of systems, depending on individual circumstances. In truly remote situations, single sideband radio, which is often unreliable, is the only option. MSS, on the other hand, has the potential to be a single, reliable communication system for use by temporary camps, boats, and research and management personnel located at permanent facilities.

Within the Department of Natural Resources, the Division of Geological and Geophysical Surveys and the Division of Forestry both have the need for communication to remote locations. Geological and Geophysical Surveys operates remote seismic monitoring stations which transmit low speed data. These must presently be located so that they can be connected by VHF to existing microwave facilities. MSS could also provide the communication link, and with MSS, the stations could be located virtually anywhere.

The Division of Forestry has responsibility for firefighting over the southern part of Alaska. Firefighters very often work in remote locations, and they have the need for two-way voice communication with their dispatch centers. The need to communicate is obviously quite critical. Various systems are presently used, depending on circumstances. MSS has the potential to substantially improve the ease and reliability of these communications.

Other Candidate Applications

Ships operated by the Marine Highways System, within the Department of Transportation and Public Facilities, have the need to communicate with shore facilities. Voice communication, presently provided through single sideband radio, is considered generally adequate, but there are some gaps in coverage. The Marine Highway System is interested in expanding its computer-based reservations system to include computer terminals and personal computers located aboard the ships. These must be linked, through a data communication circuit, to a computer ashore. MSS appears to be an ideal way to provide the necessary data communication link.

The Division of Emergency Services, which is within the Department of Military and Veterans Affairs, has a need for communication services when disasters occur. If other communication facilities are unavailable because of disaster conditions, MSS appears to provide an excellent way of establishing the vital links. Single sideband radio is presently used, but, as mentioned above, its reliability is not always adequate.

TECHNICAL FEASIBILITY

Mobile satellite service can be provided using presently available technology. The only impediments to its implementation in Alaska are approval by the responsible regulatory body, the Federal Communications Commission, and coverage of Alaska by an operational spacecraft.

Communication satellites transmitting radiated power levels high enough to be usable by mobile and transportable stations will make mobile satellite service feasible. Operation will be at UHF, in the 800 MHz range and perhaps at L-band (1.5-1.6 GHz). Direct communication links will be established between a satellite and: mobiles, transportables, gateway earth stations, base earth stations, and a control earth station. Each base earth station will serve a dispatch console, and each "gateway" will provide connection to the public switched telephone network. The control earth station, an operations center, will perform satellite and network control.

The network structure will accommodate four kinds of communication:

1. Mobile to mobile
2. Mobile to dispatcher
3. Mobile to public switched telephone network
4. Satellite and network control

The network must serve a large number of mobiles, a smaller but still large number of base stations and gateways, and the operations center.

Because UHF spectrum is in short supply, it is likely that UHF will be used only for communication with mobile units. SHF, either C-band (6/4 GHz) or Ku-band (14/12 GHz), will be used by base stations, gateways and the control station. It is possible that L-band will be used to serve some mobile units, and aeronautical mobiles in particular.

Mobile transmissions on UHF will be translated by the satellite to SHF and then retransmitted to a base station or gateway. Similarly, fixed station (base station or gateway) uplink transmissions on SHF will be translated to UHF and then retransmitted to a mobile. All mobile-to-fixed and fixed-to-mobile transmissions will involve a single hop, but mobile-to-mobile transmissions will require a double hop. One mobile's transmission on UHF will be retransmitted to the base station on SHF. It will then be switched at the dispatch console and transmitted back to the spacecraft on another SHF frequency, and retransmitted to the second mobile on yet another UHF frequency.

Satellite channels will be assigned automatically and dynamically as they are needed. Under this "demand assignment multiple access" (DAMA) approach, all functions will be performed automatically by user stations and by the operations center. The operations center will answer requests for channel assignments, make channel assignments, perform billing functions, and generally control the network.

A mobile or fixed station initiating a voice contact will use a common signalling satellite channel to automatically request service from the operations center and specify the unit being called. The operations center will assign a satellite channel from a pool of available channels and notify both requesting and called stations to switch to that channel. When the conversation is complete, the operations center will be notified so that billing functions can be completed and the channel can be returned to the pool.

The mobile satellite technology can also be used to provide data communication service. A packet-oriented service might be used to transmit sensor data, position information, or data entered from a keyboard. At low data rates, the service would probably be quite inexpensive. Under one concept, the operations center will interrogate all participating mobiles, base stations and gateways sequentially. Stations with data in memory awaiting transmission will transmit this data upon interrogation. The operations center will process the data as necessary and then send it on to the destination mobile, base station or gateway. Provision will be made for the operations center to process "alarm" signals not received in the normal interrogation sequence.

In order to make mobile satellite service technically feasible, the spacecraft must provide sufficient radiated power in the direction of the coverage area. Radiated power depends on the power available aboard the spacecraft and the gain of the spacecraft antenna. First generation satellites will involve modest antennas and no more than a few beams. Such a satellite might use a 3 to 10 meter UHF antenna. A three beam pattern covering the United States and Canada would require a 5.5 meter antenna.

Circular polarization will be used because of Faraday rotation caused by the E- and F-layers, a significant effect at 800 MHz. Further, some degree of cross polarization isolation can be achieved using left-hand circular and right-hand circular polarization. This will facilitate frequency reuse in later generation systems.

In the future, spacecraft may use very large antennas to provide a multitude of spot beams. Such a satellite may be launched around the turn of the century. NASA is planning an effort intended to lead to the development of such a spacecraft. A multiple beam configuration will allow frequency reuse, which will, in turn, mitigate the spectrum scarcity at 800 MHz. With frequency reuse, the same set of frequencies can be used in a number of different beams, but not in two adjacent beams, because interference would result where the beams overlap.

The spacecraft necessary to provide mobile satellite service will be owned and operated by a satellite carrier, which may have as owners wireline common carriers, radio common carriers, and private users. Operating within the present mobile telecommunications industry structure, this company will act as a "carrier's carrier," leasing satellite capacity to wireline common carriers (telephone companies) and radio common carriers, which will market mobile telephone service. The wireline and radio common carriers will provide equipment to their customers and will own and operate the gateways which will allow interconnection to the public switched telephone network.

The satellite carrier will also lease capacity to private users of radio service. These users will own and operate their own mobile equipment and base stations. It is anticipated that existing and new equipment suppliers will manufacture and sell mobile, portable, gateway and base station equipment and antennas.

MOBILE AND TRANSPORTABLE STATIONS

Signal-to-noise and frequency stability considerations will be paramount in the design of mobile radio units. Since the signal power received from the satellite will be small, low noise receiver front ends will be used, some antenna gain will be required, and modulation techniques will be needed that make the most of available signal power. In addition, narrow channel spacing will allow little room for frequency drift. NASA and the Jet Propulsion Laboratories (JPL) have started work aimed at developing technology to meet these requirements.

A likely analog voice modulation technique is amplitude companded single sideband (ACSB). Efficient spectrum utilization is necessary for mobile satellite service, and ACSB requires only 4 or 5 kHz channel bandwidth. In addition, ACSB provides very respectable signal-to-noise performance, and it is modest in its use of the limited power available aboard the spacecraft.

Since guard bands will be small, frequency stability is critical. It is likely that a central frequency reference will be used, and all stations will lock to this reference. Doppler shift will be a problem in the case of aeronautical mobiles, for which special frequency correction circuitry will be required.

Low noise receiver front ends and antenna gains of 4 dBi or more will be needed. Two classes of mobile antennas, steered and non-steered, are envisioned. Non-steered antennas (4-8 dBi) will be omnidirectional with regard to azimuth. Steered antennas (with more than 8 dBi gain) will be directional with regard to azimuth and will track the satellite being used as vehicles move about. Besides providing higher gain, steered antennas will also allow more than one satellite to serve the same geographical area on the same set of frequencies. Both antenna types must provide rejection of earth reflections to avoid multi-path fading.

The value of a mobile telephone unit would be greatly enhanced if it were also capable of working with cellular systems. There is a compatibility problem, however, that arises from the likely use of ACSB modulation for mobile satellite service and the current use of wideband frequency modulation (WBFM) for cellular systems. (Cellular WBFM does not seem appropriate for mobile satellite service because it consumes 30 kHz per channel, a great deal of precious spectrum.) One solution may lie in a mobile unit which is capable of using either ACSB on mobile satellite frequencies or WBFM on cellular frequencies. Such a unit would be more expensive but, for some users, might be worth the additional cost.

Transportable stations, capable of being carried by a person, will be similar to mobile stations, except that transportable antennas will be able to incorporate high gain without being steerable. It will be possible to set up a transportable antenna and direct it toward the satellite. The antenna will not need to be repointed until it is moved to a new location.

REGULATORY SITUATION

The 1979 World Administrative Radio Conference (WARC) authorized mobile satellite operation in the 806-890 MHz range in Region 2, which includes North America and South America. NASA had originally suggested such a frequency allocation during preparations for the WARC, and, as a result, the United States proposed it at the conference.

In November 1982, NASA petitioned the FCC to allocate 20 MHz in the same frequency range for mobile satellite service in the United States. In 1983, in advance of any decision on frequency allocation, Skylink Corporation and Mobile Satellite Corporation submitted applications for developmental mobile satellite licenses to the FCC.

As a result of the NASA petition, the companies' applications, and the interest expressed by other parties, the Commission, in January 1985, released a Notice of Proposed Rulemaking that:

- proposed to allocate certain frequencies in the 806-890 MHz band to mobile satellite service;

- proposed to use L-band for mobile satellite services that cannot be accommodated at 800 MHz;

- proposed to use SHF for the "backhaul" to base stations and gateways;

- solicited comments from interested parties; and

- solicited applications from carriers who wish to provide mobile satellite service.

Present 806-890 MHz frequency allocations include four bands that are held in reserve for future use. These are: 821-825, 845-851, 866-870 and 890-896 MHz. NASA's 1982 petition suggested that two of these (821-825 and 866-870 MHz) be allocated to mobile satellite service and two (845-851 and 890-896 MHz) be held in reserve until 1990, when they would be allocated to either terrestrial or mobile satellite service.

The FCC, in its Notice of Proposed Rulemaking, proposed to allocate 821-825 and 866-870 MHz to mobile satellite service as proposed by NASA. Under the Commission proposal, 845-851 and 890-896 MHz would continue to be held in reserve. The FCC invited interested parties to comment on this particular allocation. Comments and reply comments were submitted. The bands under consideration are largely the same as those proposed for use in Canada. This overlap should facilitate cooperation between the two countries.

The Commission also invited applications from all carriers interested in providing mobile satellite service, and 12 applications were filed in April 1985. The Commission has stated that it will probably license only one mobile satellite carrier.

The applications' salient points are summarized in Table 1. The applications that appear to have the most promise for Alaska are the ones that propose the most extensive Alaskan coverage and the most westerly orbital positions. These are the applications submitted by:

Hughes Communications Mobile Satellite Services, Inc.
Mobile Satellite Corporation
Mobile Satellite Service, Inc.
North American Mobile Satellite, Inc.
Omninet Corporation
Skylink Corporation

TABLE 1. Characteristics of Proposed Systems.

Applicant	800 MHz	1.5 GHz	Proposed orbital positions (degrees west longitude)	Alaska Coverage
Global Land Mobile Satellite, Inc.	Yes	Yes	94°, 129°	Southcentral
Globesat Express	Yes	No	*	Most
Hughes Communications Mobile Satellite Services, Inc.	Yes	Yes	135°	Most
MCCA American Satellite Service Corp.	Yes	No	96°	Southeast and Southcentral
McCaw Space Technologies, Inc.	Yes	Yes	101°	East and South
Mobile Satellite Corp.	Yes	Yes	85°, 125°	Most
Mobile Satellite Service, Inc.	Yes	Yes	85°, 125°	Most
North American Mobile Satellite, Inc.	Yes	No	129°	Most
Omninet Corp.	Yes	Yes	89°, 119°	Most
Satellite Mobile Telephone Co.	Yes	Yes	75°, 120°	Railbelt
Skylink Corp.	Yes	Yes	75°, 136°	Most
Wismer & Becker Contracting Engineers/ Transit Communications, Inc.	No	Yes	80°, 113°	Most

* Uses 50 "small, inexpensive" satellites in random, nongeosynchronous orbits.

SHADOW ANALYSIS

Even if Alaska is illuminated at adequate power levels by an MSS spacecraft, effective utilization of the spacecraft can be disrupted by terrain shadowing. This phenomenon will occur when terrain features block or disrupt the radio path between the spacecraft and the mobile or portable unit. Shadowing has the potential to be a serious problem for Alaska because, at northern latitudes, communication satellites in geosynchronous orbit appear at low elevation angles; i.e., they appear close to the horizon.

The shadowing problem has been studied carefully by means of a graphical technique which uses topographic maps. The results of this work indicate that shadowing is not likely to be a serious problem on most of the Alaska highway system or on the Alaska Marine Highway System.

The technique uses a set of rulers which can be used on standard topographic quadrangles available from the U.S. Geological Survey. The rulers take into account the properties of radio propagation and enable one to quickly determine whether a radio path exists between a particular point on a map and a spacecraft in a particular orbital position. This technique does not give precise information on whether a radio path exists to/from a specific point on the highway. Instead, it will provide an estimate of the fraction of a highway's miles which are shadowed.

Construction of Rulers

Each ruler is calibrated for a particular satellite elevation angle; e.g., one ruler for 10° elevation, one ruler for 11° elevation, etc. For each elevation angle, there is a vertical height which corresponds to each horizontal distance. The relationship is:

$$h = 5{,}280\ d \tan \theta$$

where

h = vertical height (in feet)

d = horizontal distance (in miles)

θ = elevation angle

A ray originating from a point on the earth's surface at elevation angle θ will just clear an obstacle of height h located at distance d.

Each ruler is designed to be used with topographic maps of a particular scale and a particular contour interval. The ruler's horizontal scale is the same as the map's scale. The ruler's vertical scale is based on the relationship $h = 5{,}280d \tan \theta$ and the map's scale. The calibration interval for the vertical scale should be the same as the map's contour interval.

A ruler of this type can be used to determine whether a ray originating at elevation angle θ from a point on the earth's surface will clear all of the terrain features along its path. If one is interested in a particular point on a highway and a satellite which appears at a certain azimuth and elevation, one can place the "zero" of the ruler at the point in question and lay the edge of the ruler along a line at the appropriate azimuthal angle. By comparing the vertical scale of the ruler with the map contour lines that the ruler edge crosses, it is possible to quickly determine whether the corresponding ray clears all of the terrain features along its path.

Improvement for Fresnel Zone Clearance

The type of ruler described above can be improved to provide for Fresnel zone clearance. In constructing the ruler, the required Fresnel zone clearance should be added to the vertical height calculated using $h = 5{,}280\ d \tan \theta$. For first Fresnel zone clearance, for example, the clearance radius is given by:[12]

$$R = 2{,}280 \sqrt{d_1\ d_2/F(d_1 + d_2)}$$

where

R = clearance radius (in feet)

d_1 = distance between terrain obstruction and mobile (in miles)

d_2 = distance between terrain obstruction and satellite (in miles)

F = frequency (in MHz)

Since $d_1 << d_2$

$$R \cong 2{,}280 \sqrt{d_1/F}$$

Thus, to construct a ruler providing for first Fresnel zone clearance, the equation is:

$$h = 5{,}280 \; d \tan \theta + 2{,}280 \sqrt{d/F}$$

where

h = vertical height in feet

d = horizontal distance in miles

F = frequency in MHz

θ = elevation angle

Procedure and Results

To use the graphical method to analyze shadowing problems on a particular highway, one needs a topographic map showing the highway, a ruler which has been constructed using the appropriate elevation angle, and a drafting machine (a mechanical arm with a straightedge which maintains a constant angle relative to the edge of a drawing board). The topographic map and the drafting machine are secured on a drawing board. The straightedge on the drafting arm is set to the azimuthal angle of the satellite for the highway in question. Then, with the ruler placed on the straightedge and the "zero" of the ruler placed at a point on the highway, it is possible to determine whether a radio path exists by comparing the marks on the ruler with the contour lines on the map.

Starting from the "zero" of the ruler, count contour lines and also count marks on the ruler. If, at any point along the ruler's edge, the number of contour lines counted exceeds the number of marks counted, there is a shadowing problem. If at all points along the ruler's edge, the number of marks counted exceeds the number of contour lines counted, a radio path exists.

With practice, it is possible to run the "zero" of the ruler along the highway and quickly determine where along the highway shadowing problems exist.

This technique has been used to investigate shadowing problems on a number of highways in Alaska for a satellite whose orbital position is 125°W. When results were "borderline" (i.e., the map contour interval matched the ruler vertical scale interval closely), it was assumed that shadowing would occur. Two of the highways have also been optically field checked using a compass and an inclinometer for shadowing. The graphical results and the field results for the two highways (the Parks Highway and the Seward Highway) are shown in Table 2. For both highways, field measurements showed less shadowing than graphical measurements. This is consistent with the pessimistic approach described above.

During the field work, it was noted that, in some cases, small terrain features close to the highway had been missed by the graphical procedure. This happens when the terrain feature is smaller than the contour interval of the topographic map used. In some cases, these features cause shadowing undetected by the graphical technique.

As indicated in Table 3, for most of the state's highways, only a small fraction of total mileage is hidden from view if the spacecraft is located at 125°W. Exceptions are the Dalton Highway -- an estimated 17.3 percent of its length will be shadowed -- and the Seward Highway -- an estimated 13.2 percent of its length will be shadowed. It is estimated that 7.1 percent of the state's total highway mileage is shadowed.

The Alaska Marine Highway System routes were examined using the same graphical technique, and with one exception, no shadowing was found. The exception is in the Gastineau Channel near Juneau, where there is a possibility of shadowing.

TABLE 2. Shadowing mileage field results.

Highway	Shadowed Mileage		Total mileage (miles)	Percent of Mileage Shadowed	
	Field measured (miles)	Estimated (miles)		Field measured (percent)	Estimated (percent)
Parks	9.3	11.7	323	2.9	3.6
Seward	15.2	16.75	127	12.0	13.2
TOTALS	24.5	28.45	450	5.4	6.3

TABLE 3. Shadowing mileage estimates.

Highway	Estimated mileage shadowed (miles)	Total highway mileage (miles)	Percentage of miles shadowed (percent)
Alaska	3.25	232	1.4
Dalton	72.0	416	17.3
Edgerton and Copper River	7.5	81	9.3
Elliott	5.5	152	3.6
Glenn	15.0	189	7.9
Haines	0.0	87	0.0
Parks	11.7	323	3.6
Richardson	23.0	364	6.3
Seward	16.75	127	13.2
Steese	9.0	162	5.6
Sterling	4.0	136	2.9
Taylor	10.0	161	6.2
Tok Cutoff	2.5	125	2.0
TOTALS	180.2	2,555	7.1

ECONOMIC ANALYSIS

The economic feasibility of mobile satellite service can be evaluated by developing cost estimates for the use of MSS and the conventional systems it might replace. Such cost estimates are compared here for some of the candidate applications. Unfortunately, some of the costs of using MSS cannot be accurately estimated at this time. Where this is the case, a range of estimates is used.

Where communication services are presently provided along the state's highways, along the coast and in remote areas, VHF or UHF systems supported by microwave or high frequency single sideband systems are used. In this section the costs of microwave-VHF (MW/VHF) and single sideband (SSB) systems are compared with the cost of mobile satellite service (MSS).

The costs of the three options vary with three independent variables:

m = annual minutes of use
s = number of repeater sites needed
u = number of terminal units in service

MSS will involve charges based on minutes of use, and MW/VHF requires the use of repeater sites. The cost of each of the three options will depend on the number of mobile and portable terminal units in service. It is assumed for purposes of comparison that each system includes a single base station and a number of mobile and/or portable terminal units.

The annual cost of operating a MSS system is:

$$A + Bm + Cu$$

where

A = annualized cost of a base station
B = cost of one minute of satellite use
C = annualized cost of a terminal unit

The annual cost of operating a MW/VHF system is:

$$D + Es + Fu$$

where

D = annualized cost of base/dispatch facility

E = annualized cost of a repeater site

F = annualized cost of a terminal unit

The annual cost of operating a SSB system is:

$$G + Hu$$

where

G = annualized cost of a base station

H = annualized cost of a terminal unit

Table 4 is a summary of the three cost expressions and the definitions of the independent variables and constants.

Using these expressions, it is clear that MSS will be less costly than MW/VHF when:

$$A + Bm + Cu < D + Es + Fu$$

Equivalently,

$$(A-D) + Bm + (C-F)u < Es$$

or

$$(A-D)\left(\frac{1}{s}\right) + B\left(\frac{m}{s}\right) + (C-F)\left(\frac{u}{s}\right) < E$$

TABLE 4. Summary of economic analysis approach.

<u>Annualized Cost Expressions</u>

MSS :	A + Bm + Cu
MW/VHF:	D + Es + Fu
SSB :	G + Hu

<u>Independent Variables</u>

m = annual minutes of use

s = number of repeater sites needed

u = number of terminal units in service

<u>Constants</u>

A = annualized cost of MSS base station

B = cost of one minute of MSS satellite use

C = annualized cost of MSS terminal unit

D = annualized cost of MW/VHF base/dispatch facility

E = annualized cost of MW/VHF repeater site

F = annualized cost of MW/VHF terminal unit

G = annualized cost of SSB base station

H = annualized cost of SSB terminal unit

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where m/s is annual minutes of use per repeater site and u/s is number of terminal units per repeater site. This form of the inequality is most convenient when considering mobile radio service along a highway.

Similarly, MSS will be less costly than SSB when

$$A + Bm + Cu < G + Hu$$

or

$$Bm + (C-H)u + (A-G) < 0$$

ESTIMATION OF CONSTANTS

There are 12 companies that want to construct, launch and operate one or more MSS satellites. The applications submitted by these companies are helpful in estimating the values of the constants A, B and C. All costs that follow are in 1985 dollars.

Base Station Cost

Constant A is the annualized installed cost of a base station used for voice dispatch purposes. In its FCC application,[1] Skylink Corporation estimates that the installed cost of a base station will be $60,000 if it is used with Skylink C service and $125,000 if it is used with the Skylink B service. Skylink C service uses 800 MHz and Skylink B uses 1.5 GHz.

North American Mobile Satellite, Inc., addresses the same question in its application.[2] The company says that, for gateway and dispatch earth stations, "installed cost should be in the $50,000 to $100,000 range."

Since a base station installation will be a FSS earth station using either C-band or Ku-band and some terminal equipment, both of these cost estimates seem reasonable. For present purposes, it will be assumed that the installed cost of a base station will be between $50,000 and $125,000, and probably about $75,000. Assuming that the cost of capital is 4 percent and equipment life is 10 years,[10] and assuming that the annual maintenance cost is 3 percent of installed cost, the corresponding annualized cost will be between $7,664 and $19,161, and probably about $11,496.

Cost of Satellite Use

MSS users will pay for satellite use based on minutes of use. In its application,[1] Skylink projects use charges in the range of 14 to 42 cents per minute. For Skylink A service, a 1.5 GHz service that can be used by transportable stations with fixed pointed antennas, the charge will be 14 cents per minute. For Skylink B service, a 1.5 GHz service that can be used by mobile stations with steered antennas, the company projects 28 cents per minute, and for Skylink C service, an 800 MHz service that can be used by mobile units with omnidirectional antennas, the charge will be 42 cents per minute. Skylink's additional network service and maintenance charges will be neglected here. These are expected to be small relative to other costs.

Mobile Satellite Corporation estimates in its application[3] that the day rate for satellite use will be 22.5 cents per minute for UHF stations using directional antennas and 90 cents per minute for UHF stations using omnidirectional antennas.

McCaw Space Technologies, Inc., proposes business day rates and peak rates.[4] Peak rates apply Monday through Friday, 7:00 a.m. to 9:00 a.m. and 4:00 p.m. to 6:00 p.m. Business day rates apply Monday through Friday, 9:00 a.m. to 4:00 p.m. Peak rates are 50 cents per minute for a fixed (transportable) station and 75 cents per minute for a mobile station. Business day rates are 40 cents per minute for a fixed station and 60 cents per minutes for a mobile station. In addition, users would pay a $50 per month basic access charge.

Wismer & Becker Contracting Engineers and Transit Communications, Inc., propose a rate structure that involves fixed monthly charges or per minute charges.[5] For a mobile unit with low gain antenna, the rate is $1,349 per month or $3.75 per minute of satellite use. For a mobile unit with medium gain antenna, the rate is $175 per month or 49 cents per minute, and for a fixed unit with high gain antenna, the rate is $95 per month or 26 cents per minute.

Global Land Mobile Satellite, Inc., in its application suggests a rate of 10 cents per tenth of a minute, or, for present purposes, $1.00 per minute.[6]

Omninet Corporation projects peak and off-peak rates. In addition to a fixed charge of $27 per month, peak use would cost 1 cent per call plus 25 cents per minute, and off-peak use would cost 0.5 cent per call and 12.5 cents per minute.[7]

The applicants propose a wide range of rates and a variety of rate structures. For present purposes it will be assumed that the cost of satellite use will be based strictly on minutes of use. There is a good deal of uncertainty about what the rates will be. But, ultimately, rates will depend on the cost of building, launching and operating a satellite as well as demand for the service. They will also depend on what regulatory constraints are placed on the satellite carrier. Here a wide range of rates, 20 cents to $1.00 per minute, will be considered.

Terminal Unit Cost

The MSS satellite carrier will probably not manufacture terminal equipment. Nevertheless, a number of applicants have estimated the costs of mobile and transportable stations.

Skylink estimates that a fixed or transportable unit capable of using Skylink A service will cost about $3,100. A mobile unit with steered antenna capable of using Skylink B service will cost $4,000, and a mobile unit with omnidirectional antenna capable of using Skylink C service will cost $2,250.[1]

Hughes Communications Mobile Satellite Services, Inc., estimates in its application that a mobile terminal will cost between $1,500 and $3,500.[8]

MCCA American Satellite Service Corporation projects that a mobile unit will cost $1,000 and a transportable unit $2,500.[9]

Omninet Corporation suggests that a mobile unit will cost $1,250.[7]

North American Mobile Satellite, Inc. (NAMSAT), says in its application,[2] "other than the antenna for the satellite system, the costs of the mobile terminal should be much the same for both cellular terrestrial and satellite-based services, if manufacturing quantities in the satellite version can be sustained. At this time, the cellular terminal costs are in the $1,000 to $2,000 range, and are expected to be lower by the time NAMSAT is launched."

In light of the above, it will be assumed here that costs for transportable and mobile units will be between $2,000 and $3,500. A unit's annualized cost, including maintenance will range between $306 and $536.

Costs of Terrestrial Systems

The costs of MW/VHF and SSB systems are well known because such systems are in widespread use. For comparison purposes, the following installed equipment costs will be used:

MW/VHF	
Base dispatch communications	$ 39,700
Repeater	116,160
Mobile unit	2,000
Portable unit	1,500
SSB	
Base station	8,000
Mobile unit	3,000
Transportable unit	2,500

The installed cost estimate for a MW/VHF repeater has been developed with the assistance of the Alaska Division of Telecommunications Operations. Table 5 shows the components of the cost estimate. The "base/dispatch communications" item includes the communications facilities needed at the dispatch location. The components of its cost estimate are given in Table 6.

TABLE 5. Estimated cost for microwave repeater, helicopter access, 6 channels.

	Tower (20 foot stub)		$ 2,500
2	Radios @ $11,000		22,000
2	Antennas @ $2,500		5,000
	Multiplex		2,300 + $1,300/channel
	common equipment	$ 1,500	
	channel shelf	300	
	channel card	600 each	
	signaling termination shelf	500	
	signaling termination card	700 each	
	Erection and transportation		15,000
2	Buildings (generator and communications) @ $8,000		16,000
	Generator		8,000
	Solar plant		2,500
	Battery plant		10,000
	Battery charger		2,500
	Installation		5,760
	12 man days @ $50/hr and $80 per diem		
	VHF base station		2,500 each
	VHF antenna		300 each
	TOTAL		$116,160

TABLE 6. Estimated cost for microwave-VHF base/dispatch communications facilities (12 channel).

Tower (20 foot stub)		$ 2,500
Radio		11,000
Antenna		2,500
Multiplex		2,300 + 1,300/channel
Common equipment	$ 1,500	
Channel shelf	300	
Channel card	600 each	
Signaling term shelf	500	
Signaling term card	700 each	
Erection		5,000
Installation		800
20 man days @ $50/hour		
TOTAL		$ 39,700

Using these installed costs, a cost of capital of 4 percent, and equipment life of 10 years, and an annual maintenance expense of 3 percent of installed cost, the following annualized costs result:

<u>MW/VHF</u>	
Base dispatch facility (D)	$ 6,085
Repeater (E)	17,806
Mobile unit (F_1)	306
Portable unit (F_2)	229
<u>SSB</u>	
Base station (G)	1,226
Mobile unit (H_1)	459
Transportable unit (H_2)	383

The values estimated for all 10 constants are summarized in Table 7.

COST COMPARISONS

The cost of MSS can be compared with the cost of existing systems by using the expressions and cost estimates developed above. This comparison is carried out in this section for four of the six candidate applications which have been identified. The four applications are:

- Highway - voice
- Remote - voice
- Marine highway - voice
- Emergency services - voice

Cost comparisons are not performed for the two data applications because cost estimates for MSS data terminal equipment and transponder time are not generally available.

TABLE 7. Summary of constants and estimated values.

Constant	Description	Estimated value
A	Annualized cost of MSS base station	$ 11,496
B	Cost of one minute of MSS satellite use	0.20-1.00
C	Annualized cost of MSS terminal unit	306-536
D	Annualized cost of MW/VHF base/dispatch facility	6,085
E	Annualized cost of MW/VHF repeater site	17,806
F_1	Annualized cost of MW/VHF mobile terminal unit	306
F_2	Annualized cost of MW/VHF portable terminal unit	229
G	Annualized cost of SSB base station	1,226
H_1	Annualized cost of SSB mobile terminal unit	459
H_2	Annualized cost of SSB transportable terminal unit	383

Highway - Voice

As just shown, MSS will be less costly than MW/VHF service for mobile voice service along a highway when

$$(A-D)\frac{1}{s} + B\frac{m}{s} + (C-F_1)\frac{u}{s} < E$$

Recall that s is the number of microwave repeater sites in a given system, m/s is annual minutes of use per repeater site, and u/s is the number of mobile terminal units per repeater site.

Substituting constant values from Table 7

$$5411\frac{1}{s} + B\frac{m}{s} + (C-306)\frac{u}{s} < 17{,}806$$

If we are considering a section of highway that requires 10 microwave repeaters, s = 10, and we have

$$541 + B\frac{m}{s} + (C-306)\frac{u}{s} < 17{,}806$$

The value of B is in the range of \$0.20 to \$1.00, and the value of C is between \$306 and \$536.

In the low cost case, where B = \$0.20 and C = \$306, the inequality becomes

$$541 + 0.20\frac{m}{s} < 17{,}806$$

or

$$\frac{m}{s} < 86{,}325$$

This means that MSS will be less costly than MW/VHF if the use per repeater station is less than 86,325 minutes per year or 236 minutes per day.

In the high cost case, where B = \$1.00 and C = \$536, the inequality becomes

$$541 + \frac{m}{s} + 230\frac{u}{s} < 17,806$$

If we assume 10 mobile units on each section of highway served by one repeater, u/s = 10, and

$$541 + \frac{m}{s} + 2,300 < 17,806$$

or

$$\frac{m}{s} < 14,965$$

In this case, MSS will be less costly than MW/VHF only if the use per repeater station is less than 14,965 minutes per year or 41 minutes per day, a rather low figure.

Thus, the economic attractiveness of MSS for mobile voice service along Alaska's highways is quite dependent on the actual cost of transponder time and actual installed costs for mobile terminal units.

<u>Remote - Voice and Emergency Services - Voice</u>

MSS will be cheaper than SSB for remote and emergency transportable voice communication when

$$Bm + (C-H_2)u + (A-G) < 0$$

Substituting constant values from Table 7

$$Bm + (C-383)u + 10,270 < 0$$

The value of B is in the range of \$0.20 to \$1.00 and the value of C is between \$306 and \$536.

In the low cost case, where B = \$0.20 and C = \$306, the inequality becomes

$$0.20m - 77u + 10,270 < 0$$

Even if we assume 100 transportable units in the field ($u = 100$), then

$$0.20m + 2,570 < 0$$

and it is impossible for the inequality to be satisfied for positive values of m.

Since, even in the low cost case, the inequality is not satisfied, it appears that MSS will not be cheaper than SSB for remote transportable voice communication.

Marine Highway - Voice

MSS will be cheaper than SSB for Marine Highway voice service when

$$Bm + (C-H_1)u + (A-G) < 0$$

Substituting constant values from Table 7

$$Bm + (C-459)u + 10,270 < 0$$

The value of B is between \$0.20 and \$1.00, and the value of C is between \$306 and \$536.

In the low cost case, where B = \$0.20 and C = \$306, we have

$$0.20m - 153u + 10,270 < 0$$

Assuming 10 mobile units ($u = 10$), the inequality reduces to

$$0.20m + 8,740 < 0$$

It is clear that the inequality cannot be satisfied for positive values of m. Thus, for Marine Highway voice communication, MSS will not be cheaper than SSB.

Of the four applications examined in this section, MSS is economically attractive for only one. For this application, mobile voice service along the highway, MSS will be less costly than the present MW/VHF service if the costs of transponder use and mobile terminal units are in the lower portions of the presently anticipated ranges.

ESTIMATE OF MSS COSTS FOR FOUR APPLICATIONS

In order to assist the reader in assessing the cost of MSS, capital and operating cost estimates have been developed for the four applications just discussed.

- Highway - voice
- Remote - voice
- Marine Highway - voice
- Emergency services - voice

Three cost figures are given: capital cost, operating cost and annualized cost. Capital cost is the initial cost of purchasing and installing necessary equipment. Operating cost is the annual cost of operating and maintaining the system. Annualized cost is the sum of annualized capital cost and annual operating cost. Capital cost is annualized assuming an equipment life of 10 years and a real interest rate of 4 percent.

Table 8 gives capital, operating and annualized cost for each of the applications. The cost estimates are based on the following assumptions:

- The installed cost of a base station/dispatch facility is $75,000
- Transponder use costs $0.50 per minute

- The installed cost of a mobile or portable terminal unit is $2,775
- Annual maintenance cost is 3 percent of installed equipment cost

For each application, representative values for minutes of use and number of terminal units have been chosen. The cost estimates are based on these values.

TABLE 8. Capital, operating and annualized cost estimates.

Scenario	Annual minutes of use (m)	No. of terminal units (u)	Cost estimates ($)		
			Capital	Operating	Annualized
Mobile Highway - voice	110,000	20	130,500	58,915	75,004
Remote - voice	110,000	200	630,000	73,900	151,572
Marine Highway - voice	110,000	10	102,750	58,082	70,750
Emergency Services - voice	36,000	10	102,750	21,082	33,750

CONCLUSIONS

A number of promising Alaskan applications of MSS have been identified. In these applications, MSS would provide more reliable and, in some cases, more convenient service than that which is presently available. While there are no substantial technical barriers to the use of MSS in these applications, the provision of MSS in Alaska will depend on FCC decisions to allocate the necessary frequencies and license a carrier that will provide Alaskan coverage. Shadowing is not expected to be a serious problem along Alaskan highways and along the Alaska Marine Highway. The only exceptions are the Dalton Highway -- an estimated 17.3 percent of its length will be shadowed -- and the Seward Highway -- an estimated 13.2 percent of its length will be shadowed.

Table 9 lists each of the six candidate applications that have been identified. For each application, the advantages and disadvantages of using MSS are listed, and, where service is presently being provided, the type of existing system is shown, as well as whether or not MSS will be cheaper.

It has not been possible to do cost comparisons for two of the six applications, but, of the remaining four, there is only one application for which MSS may offer a cost advantage. This application is highway mobile voice service. The cost issue should be reexamined when MSS is closer to implementation and costs can be more accurately estimated.

The real appeal of MSS is not in the area of cost -- it is in reliability and convenience, particularly in applications where HF/SSB is presently used. There is no present day technology which will allow one to move into a remote area and establish a reliable voice communication link within just a few minutes. It is this capability that offers dramatic potential for remote area and emergency communications. MSS also promises the most reliable voice and data communications for the Alaska Marine Highway.

For highway mobile voice service, MSS must compete with the present microwave-VHF based system. MSS would eliminate the need for mountaintop repeater sites, thus reducing maintenance expense and possibly improving reliability. On the other hand, if MSS were used on some portions of the highway system and MW/VHF on other portions, it would be advisable to use a "compatible" mobile terminal unit; i.e., one capable of working with either system. It is not presently known whether such units will be commercially available or what their cost will be.

TABLE 9. Candidate application summary.

Candidate Application	Existing System	Is MSS Cheaper?	MSS Advantages and Disadvantages
1. Highway - voice Dept of Public Safety DOT&PF EMS	Microwave/VHF (Some gaps exist)	Depends on ultimate MSS costs	Advantage: No remote sites No related maintenance -- potential for high reliability Disadvantage: Incompatible with existing system Cost dependent on usage
2. Remote - voice Dept of Fish & Game DNR	Usually SSB	No	Advantage: Quick and easy setup More reliable than HF/SSB Disadvantage: More costly than HF/SSB
3. Remote - low speed data DNR	Microwave/VHF	?	Advantage: Remote monitoring stations can be located anywhere within view of satellite (presently restricted to within VHF range of a microwave site) Disadvantage: Cost dependent on usage
4. Marine Highway - voice DOT&PF	SSB	No	Advantage: More reliable than HF/SSB Disadvantage: More costly
5. Marine Highway - data DOT&PF	None	?	Advantage: No existing system can handle this traffic MSS may be cheaper than installing any other new system
6 Emergency services Dept of Military and Veterans Affairs	SSB	No	Advantage: Quick and easy to set up More reliable than HF/SSB Disadvantage: More costly than HF/SSB

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10. So that all costs can be compared, one time costs are converted to equivalent annual costs. This conversion is done in constant 1985 dollars, assuming 10 year equipment life and a real interest rate of 4 percent.

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