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THE AMSC MOBILE SATELLITE SYSTEM:
DESIGN SUMMARY & COMPARATIVE ANALYSIS

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ABSTRACT

Mobile satellite communications will be provided in the United States by the American Mobile Satellite Consortium (AMSC). Telesat Mobile, Inc. (TMI) and AMSC are jointly developing MSAT, the first regional Mobile Satellite Service (MSS) system. MSAT will provide diverse mobile communications services – including voice, data and position location – to mobiles on land, water, and in the air throughout North America.

This paper briefly describes the institutional relationships between AMSC, TMI and other organizations participating in MSAT, including the Canadian Department of Communications and NASA. The paper reviews the regulatory status of MSAT in the United States and international allocations to MSS. The paper then describes the baseline design. It concludes by comparing the baseline MSAT FDMA system architecture to alternatives, including CDMA and TDMA.

INTRODUCTION

The American Mobile Satellite Consortium (AMSC), incorporated at the JPL Mobile Satellite Conference on May 3, 1988, will soon receive the U.S. domestic Mobile Satellite Service (MSS) license from the Federal Communications Commission. This license will authorize AMSC to construct and operate a domestic MSS system to serve North America in conjunction with Telesat Mobile, Inc. (TMI), the Canadian MSS operator.

MSAT, the MSS system under development by AMSC and TMI, provides diverse mobile satellite services through high-performance satellites. MSAT consists of four primary elements: the space segment, Network Operations Centers, mobile terminals, and hub terminals. This paper reviews the institutional relationships behind MSAT, describes the MSAT system, and compares the MSAT system architecture to alternative architectures.

INSTITUTIONAL REVIEW

MSS is regulated in the United States by the Federal Communications Commission (FCC), which has determined that the service will be provided domestically by the American Mobile Satellite Consortium, Inc. (AMSC), owned by eight stockholders:

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

McCaw Space Technologies, Inc.
Mtel Space Technologies Corporation
Satellite Mobile Telephone Co.
Transit Communications, Inc.

Each AMSC stockholder has placed \$5 million into a joint escrow account. This \$40 million account is being used for initial capitalization of the consortium.

AMSC will own and operate the U.S. MSS space segment and Network Operations Center. AMSC is to operate its MSS system as a carrier's carrier.

NASA has offered to provide launch services to AMSC in return for the use of some of the capacity of the first generation mobile satellite system for two years. NASA will use this capacity to perform technology experiments and to enable government agencies to assess the usefulness of MSS to their operations. Government applications include public safety, aviation safety, communications for wide and remote area coverage (police and border control), monitoring of hazardous material transport, and others. After two years, agencies continuing with the service will become commercial customers of AMSC.

NASA has signed Memoranda of Understanding (MOU) with ten government agencies to participate in its MSS program. Generally, each MOU requires NASA to provide channel capacity, high risk research and development, and technical assistance to the participating agency. Each agency is responsible for developing and producing its own experiment hardware and for implementing and evaluating its experiment. Participating agencies include:

*Army Corps of Engineers
Department of Interior
Federal Aviation Administration
Medlink/State of Florida
State of Alaska*

*Coast Guard
Drug Enforcement Agency
Federal Bureau of Investigation
National Communications System
USDA Forest Service*

There will be a single MSS operator in Canada: Telesat Mobile, Inc. (TMI). Telesat Canada is the leading stockholder of TMI. TMI will own and operate the Canadian space segment, a Network Operating Center, and a network of base and gateway stations.

AMSC and TMI have signed an Agreement for Cooperation providing for the development of common requirements, a spectrum utilization plan, joint satellite procurement, intercarrier leasing of surplus capacity, and cooperation in coordination of MSAT with other international systems.

The Canadian Department of Communications (DOC) has the responsibility for developing domestic telecommunications and spectrum policies throughout Canada. DOC has made a \$176 million commitment to MSS – \$30 million for hardware development, \$20 million for user trials, and \$126 million for leased capacity from TMI for Canadian government needs (Zuliani, 1988). DOC has been developing advanced MSS technology through its Communications Research Centre.

ALLOCATIONS

MSAT uses L band frequencies for communications between mobiles and satellites, and K_u band for satellite TT&C and for communications between satellites and hub terminals (the "backhaul" or "feeder link").

AMSC applied for 14 MHz of L band spectrum in each direction: 1545 to 1559 MHz (space-to-earth) and 1646.5 to 1660.5 MHz (earth-to-space). In the U.S., these bands are currently allocated to AMSS (R) on a primary basis and to generic MSS on either a co-primary or secondary basis (see Figure 1). Internationally, these bands are allocated to AMSS (R) or to LMSS (R), each primary (but not co-primary). The U.S. and Canada seek a new World Administrative Radio Conference to be held no later than 1992 to reallocate the bands requested by AMSC to generic MSS internationally (Zuliani, 1988).

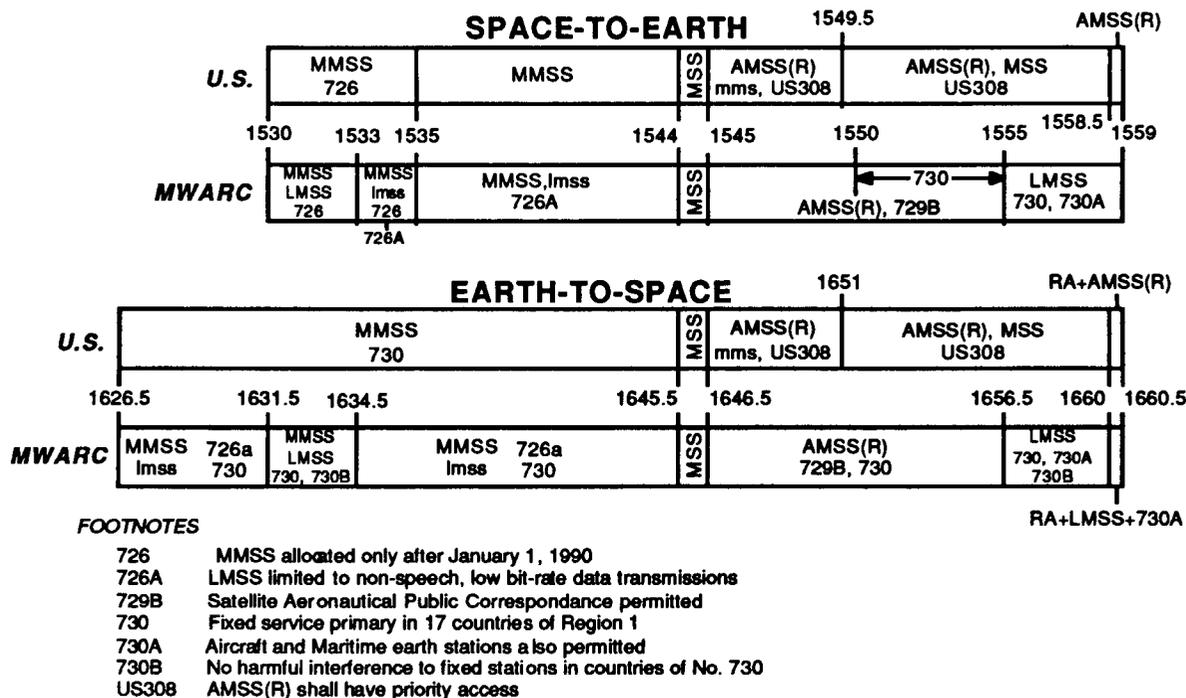


Figure 1. Domestic and international MSS allocations at L band

International coordination procedures are now under way. Coordination prevents interference with other international systems that will use portions of the bands allocated within the U.S. and Canada to MSAT, such as the Soviet Volna system and INMARSAT's aeronautical system. The coordination process may result in the availability of only a segmented sub-portion of the band allocated to MSS by the U.S. and Canada. The network architecture thus may have to accommodate a segmented band.

International and domestic radio regulations do not permit the use of L band frequencies for MSS feeder links. Higher frequencies permit fixed hub stations to point accurately at one satellite of many in the orbital arc, enabling a high degree of orbit reuse. AMSC requested K_u band frequencies for feeder link communications.

SYSTEM DESIGN (adapted from Agnew, 1988)

The system designer must maximize information throughput while satisfying the following requirements:

- Cover Canada, CONUS, Alaska (and possibly Mexico) at both L band and K_u band
- Accommodate whatever limits are placed on the system by coordination
- Support multiple gateways and base stations
- Provide priority access to emergency services
- Accommodate new technology

MSAT was designed with these requirements in mind. It consists of four basic elements: the space segment, Network Operations Centers, user terminals, and hub stations (Figure 2). Users can access the public switched telephone network through gateway stations or private networks through base stations.

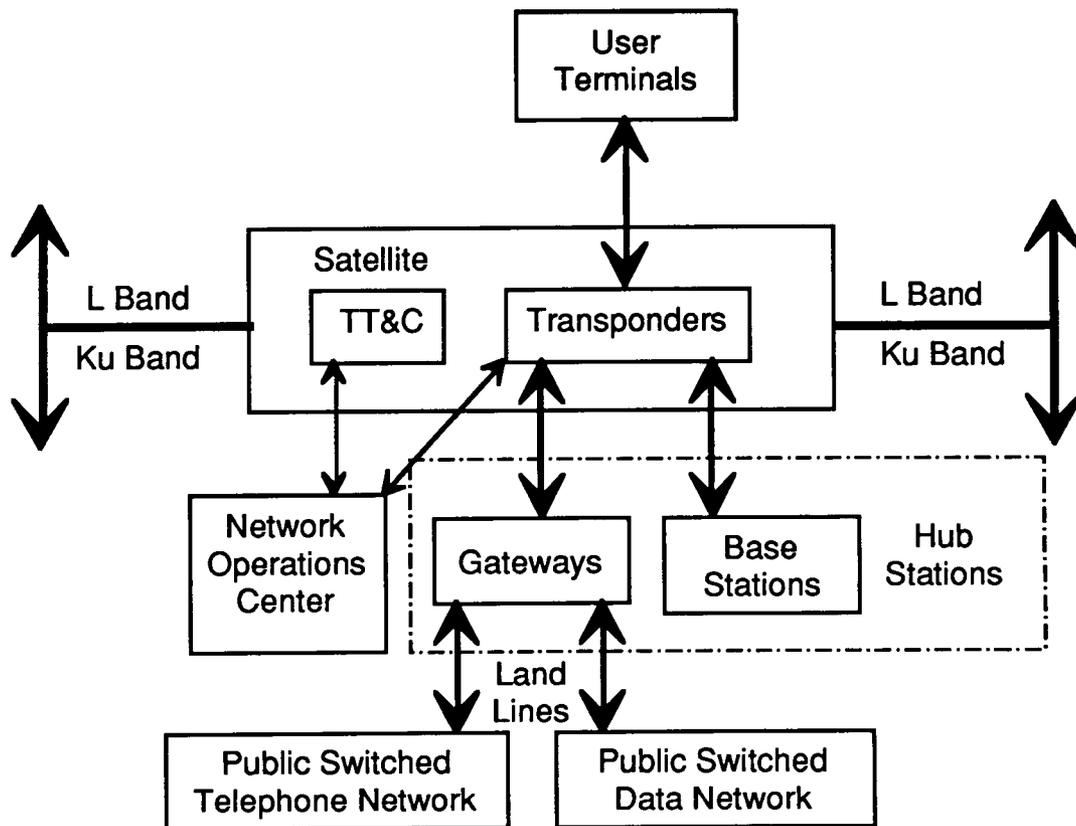


Figure 2. Network Block Diagram

All circuits are controlled by the Priority Demand Assignment Multiple Access (PDAMA) system and are routed to a K_u band gateway or base station. All L band satellite circuits are connected to K_u band feeder link circuits in the satellite. L band-to-L band circuits require two satellite hops via a gateway or base station. There is no satellite path for direct single hop L band-to-L band circuits.

AMSC and TMI will each construct and operate one K_u band Network Operations Center (NOC) for network monitoring and control and satellite TT&C. AMSC will also operate two gateway stations for test and monitoring purposes. Operational gateway stations will be constructed and operated by common carriers purchasing space segment capacity from AMSC and TMI. Base stations will be used by private network operators.

As illustrated in Figure 2, the ground segment includes the NOCs and two primary classes of earth stations: user terminals and hub stations. These elements are described below.

User Terminals

Three classes of user terminals – mobile/omni, mobile/steered, and transportable – are required because users vary widely in average air time requirements, intended use, and their vehicle's characteristics.

Mobile/omni terminals will be the lowest cost terminals, but because of the low gain of omni antennas, a relatively high satellite EIRP is required for each channel. This results in high airtime charges. Mobile/omni land and maritime terminals will be able to use antennas with 3 to 6 dBi gain.

Mobile/steered terminal antennas must be actively pointed towards the satellite. This requires determining the position of the satellite relative to the vehicle, an antenna that is directional in azimuth, and a method for steering the antenna towards the satellite. These requirements result in a higher cost terminal, but also substantial reductions in airtime charges. Mobile/steered aeronautical, land and maritime terminals are expected to have antenna gains in the 10 to 14 dBi range.

When transportable terminals can be used, both terminal cost and airtime charges are minimized. Transportable antenna gain is expected to be in the range of 15 to 22 dBi.

All three user terminal classes support voice and/or data service using ACSB or a variety of digital modulation formats. Terminal signalling and modulation standards are being developed in cooperation with manufacturers and other MSS operators.

The Priority Demand Assignment Multiple Access (PDAMA) system has a Frequency Division Multiple Access (FDMA) architecture, with Time Division Multiple Access (TDMA) used in individual channels for data communications and control. The PDAMA system communicates with a micro-controller in each user terminal to dynamically allocate spectrum and network capacity to active terminals. Despite many functional differences, user terminals share a common pool of 5 kHz channels for nearly all applications. All channels are constructed of contiguous 2.5 kHz subchannel sets; every terminal is capable of tuning to any center frequency in 2.5 kHz increments throughout the entire 14 MHz operating band.

All aeronautical terminals have at least the "core" capability defined by ICAO, 1986. The core capability is a two-way 600 bps data link and is used for air traffic control. All aviation communications, including voice, will be digital.

The aircraft antenna is expected to be a phased array system including two high gain phased arrays looking abeam and mounted 45° from the horizon on each side of the aircraft, or a single high gain antenna mounted on the top of the fuselage or tail. In addition, a single low gain hemispherical antenna can be used with at least 0 dBi gain over 360° in azimuth, above 7° elevation for level flight. These antennas are right hand circularly polarized with an axial ratio less than 6.0 dB.

Hub Terminals

The MSAT network consists of many semi-autonomous star networks. A hub station lies at the logical center of each star network. All user terminals communicate through one or more hub stations. Hubs are of two basic types: (1) gateway stations for interconnection of telephone and other traffic to the PSTN; and (2) base stations for termination of private networks at dispatch centers and monitoring and control sites. Like user terminals, all hub stations are under the control of the NOC.

Hub stations access the satellites through duplex K_u band feeder links. All hub stations have frequency agile channel modems, each able to use any of the feeder link channels.

Gateways. Gateways interconnect traffic with the public switched telephone network. They typically have a capacity of 5 to 100 or more channels. AMSC expects that service providers will install gateways throughout the country. Traffic is routed to a point of interconnection close to the final destination.

Base Stations. Hub stations used to terminate private network traffic are referred to as base stations. They are analogous functionally to base stations in the conventional private land mobile radio service. Private base stations differ in architecture from gateways only in that channels are not connected to the telephone network, except as required for private company communications. Instead, they will generally be interfaced with dispatch

consoles or SCADA control stations. AMSC expects fleet operators to install a large number of K_u band base stations across the country.

Network Operations Center

Each Network Operations Center (NOC) will communicate with all user terminals and hub stations through a K_u band RF subsystem consisting of frequency agile digital channel units. Precision time, referenced to the National Bureau of Standards, will be disseminated over network control channels to synchronize the network and to provide a public service. In addition, MSS satellite ephemeris data and real-time information concerning the status of the Global Positioning System (GPS) satellites, Loran, and other navigation systems will be disseminated for use in integrated communications/surveillance networks.

The central Priority Demand Assignment Multiple Access (PDAMA) processor, located within each NOC, controls access to the network. It monitors usage of channels and assigns channels to users. It coordinates assignment of channels in all beams on each satellite on a dynamic basis to minimize interbeam and intersystem interference. Channel assignments between user terminals and hub stations can be switched similar to the way in which cellular channels are dynamically allocated.

The entire 14 MHz allocation is available through each beam, maximizing the flexibility of the PDAMA system to dynamically respond to market variations between beams. While the same SCPC channel cannot ordinarily be reused in adjacent beams, frequencies can be reused in beams separated by at least one beam through the use of channel interleaving and interbeam isolation.

The central PDAMA processor recognizes different levels of message priority to ensure that air traffic control and other safety-of-life services receive certain access to network capacity whenever it is needed. Additional levels of priority are used as needed in the various hub stations, according to the specific end use involved.

The PDAMA system is implemented using a distributed control architecture, whereby specialized private networks, such as required for AMSS(R) networks, have their own dedicated PDAMA processor and software. AMSC will establish interface standards that will enable private networks to operate nearly autonomously.

Space Segment

The fully developed MSAT space segment consists of three high performance AMSC satellites and one TMI satellite in geosynchronous orbit. To accommodate the market demand, it is anticipated that all satellites will employ 3-axis buses with 2500 watts prime payload power, weighing 1200 kg on orbit. The nominal launch mass, including apogee stage, is 2500 kg. Each satellite will have batteries sufficient for at least 25% service capability during eclipse.

A pair of 5.5 meter diameter unfurlable reflectors each generate ten L band spot beams covering North America (Figure 3). Separate transmit and receive antennas are used to minimize the effects of passive intermodulation. Maximum aggregate linearized L band Effective Isotropic Radiated Power (EIRP) of all beams is 60 dBW; L band G/T of each beam is 3 dB/K at edge-of-coverage.

K_u band communications are subdivided into two groups: a K_u - K_u group and a K_u -L group. The K_u - K_u group is 10 MHz wide, including 5.0 MHz for initial operations and an additional 5.0 MHz for future expansion. The K_u -L group consists of 10 channels for use by the first spacecraft in each orbital slot, and 10 channels for an additional collocated spacecraft, if needed. Horizontal uplink polarization will be used by the U.S.; the opposite polarization will be used on the downlinks.

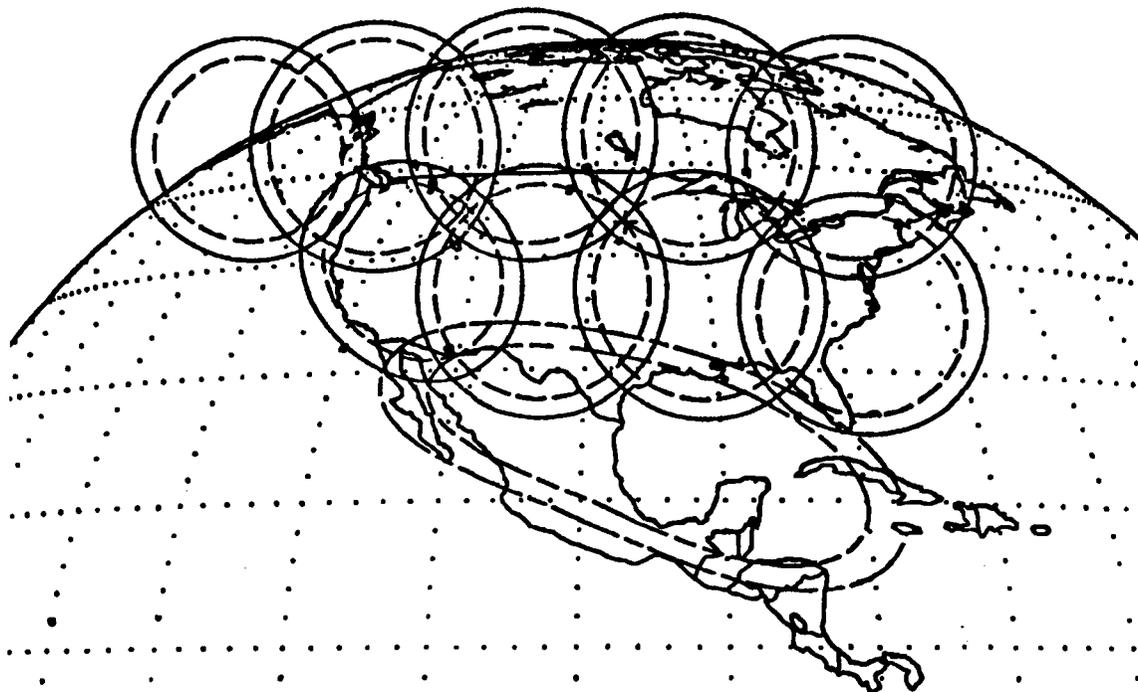


Figure 3. L Band Coverage, 101°W Orbit Location

NETWORK ARCHITECTURE COMPARISON

Code Division Multiple Access (CDMA) has been suggested as an alternative to FDMA for MSS (Jacobs, 1988). This section compares FDMA, CDMA and TDMA and concludes that a hybrid system appears well suited to MSAT.

TDMA shows little promise for MSS, other than in an FDMA system with TDMA channels for data. TDMA requires a high data rate, resulting in excessive ground station transmitter power levels. The high data rate also makes the system susceptible to delay spread degradations. The precise timing required for TDMA presents a serious problem for mobile terminals.

If an MSS system is bandwidth-limited, CDMA can exploit several characteristics of MSS to provide increased capacity (Jacobs, 1988). Figure 4 shows that MSAT becomes bandwidth limited on the forward link at a $C/(N_0W_s)$ of about 5.7 dB. At this level, the efficiency of FDMA is about the same as CDMA. If less bandwidth is available or if higher gain mobile antennas are used, the performance of CDMA surpasses that of FDMA.

Figure 4 is based on the analysis of Jacobs, 1988; a is antenna discrimination factor, ρ is polarization reuse factor, and V is voice activity factor. Figure 4 assumes 2 times FDMA frequency reuse (from exploitation of multiple spot beams, polarization diversity and channel offsets). $C/(N_0W_s)$ levels in Figure 4 are based on the calculations in Table 1 and on a directive mobile antenna G/T of -15.3 dB/K

Contiguous bands may not come out of the coordination process. MSAT might be left with sub-portions of the band requested by the U.S. and Canada. If so, a hybrid FDMA/CDMA system could provide the performance advantages of CDMA along with the flexibility of FDMA. In such a hybrid, CDMA "channels" would be used within an FDMA system.

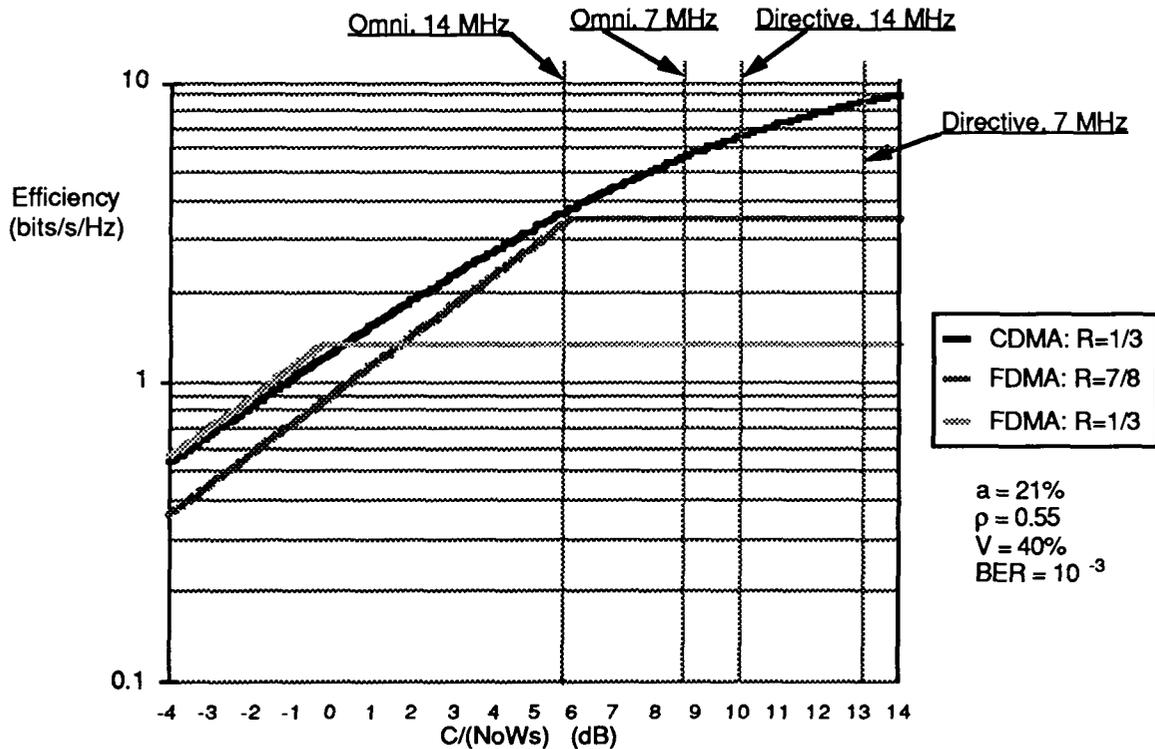


Figure 4. CDMA/FDMA Forward Link Efficiency Comparison

Satellite EIRP	60.1 dBW
Path Losses	188.8 dB
G/T	-19.7 dB/K
Downlink C/No	80.2 dBHz
Margin	3.0 dB
C/No	77.2 dBHz
Ws	68.5 dBHz
C/(NoWs)	8.7 dB

Table 1. Forward Link C/(NoWs) Calculation; Omni, 7 MHz

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