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LAND MOBILE SPECTRUM EFFICIENCY

A Plan for Federal Government Agencies to use More Spectrum-Efficient Technologies

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The Interdepartment Radio Advisory Committee (IRAC) established the Ad Hoc 210 committee to provide a forum for Federal Government agency member-representatives to present their views on telecommunication policies dealing with mobile systems. This committee provided extensive assistance to the National Telecommunications and Information Administration (NTIA) in the development of this study and plan. They described requirements of government departments and agencies for mobile radio communication services, and provided both technical and policy comments on the material drafted by NTIA technical staff. Their descriptions of technical requirements and discussions of the policy issues, and the practicality of implementing some of the proposals, contributed greatly to the initial draft of the study and plan. The IRAC approved a draft of this study and plan based on the work of the Ad Hoc committee. After completion of the IRAC effort, the study was then reviewed by NTIA, Department of Commerce and Congressional Senior Staff members. Their comments led to clarifications and amplifications of the proposed plan and procedures included in this study and plan. NTIA will continue to work closely with the IRAC as this plan is implemented so that the needs of the Federal agencies using land mobile radio technologies and services can be met through the use of spectrum-efficient and cost-effective technologies.

ABSTRACT

The National Telecommunications and Information Administration (NTIA) in the fall of 1992 was required by Congress to develop and commence implementation of a plan for Federal agencies to use wireless mobile technologies that are spectrum efficient and cost effective. In response, NTIA performed an analysis of the current Federal land mobile infrastructure with respect to spectrum efficiency and cost effectiveness. This report documents the analysis, its results and conclusions, and an implementation plan with recommended milestones.

The report includes a summary of Federal land mobile requirements and techniques such as Simplex, Repeater, Trunking, Cellular, and Emerging Wireless Technologies. The benefits of rechannelization, trunking, and other technical methods to improve spectrum utilization are explained and their spectrum efficiency advantages are quantified. Methods to introduce cost effectiveness are also introduced. One of these methods is to exploit the economy of scope that exists, for example, if the cost of a single network is less than the cost of several individual networks. Policy and regulatory methods that NTIA could use to implement the plan presented in this report include Federal use of commercial vendor services (whenever feasible), and the use of shared systems among government agencies.

KEYWORDS

Land Mobile Radio
Spectrum Efficiency
Rechannelization
Trunking Radio
Spectrum Economics
Spatial Frequency Reuse

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SECTION 1
INTRODUCTION

BACKGROUND

The National Telecommunications and Information Administration (NTIA), part of the U.S. Department of Commerce, is responsible for managing the Federal Government's use of the radio spectrum. NTIA establishes policies concerning frequency assignment, allocation, and use, and provides the various departments and agencies with guidance to ensure that their conduct of telecommunication activities is consistent with these policies. In addition, NTIA serves as the President's principal advisor on telecommunication policies pertaining to the Nation's economic and technological advancement and to the regulation of the telecommunications industry. NTIA develops executive branch views to ensure that policy is effectively presented to Federal agencies, the Federal Communications Commission (FCC), Congress, and the public.

Congress passed the Telecommunications Authorization Act to authorize appropriations for NTIA, and for other purposes. Title 1 of this act is referred to as the National Telecommunications and Information Administration Organization Act (NTIAOA). NTIAOA requires NTIA to implement a plan for Federal agencies with existing mobile radio systems to use more spectrum-efficient technologies that are at least as spectrum-efficient and cost-effective as readily available commercial mobile radio systems and provide a report to Congress by October 1, 1993, summarizing the plan.[1] The specific provisions of the act are as follows.

> (3) SPECTRUM PLAN. — By October 1, 1993, the Secretary of Commerce shall adopt and commence implementation of a plan for Federal agencies with existing mobile radio systems to use more spectrum-efficient technologies that are at least as spectrum-efficient and cost-effective as readily available commercial mobile radio systems. The plan shall include a time schedule for implementation.
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> (4) REPORT TO CONGRESS. — By October 1, 1993, the Secretary of Commerce shall submit to the Committee on Commerce, Science and Transportation of the Senate

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[1] TITLE I — *National Telecommunications and Information Administration, Telecommunications Authorization Act*, Short Title: *National Telecommunications and Information Administration Organization Act (NTIAOA)*, 47 U.S.C. 901 et seq.

and the Committee on Energy and Commerce of the House of Representatives a report summarizing the plan adopted under paragraph (3), including the implementation schedule for the plan.

NTIA, its predecessor agencies, and its interagency advisory group, the Interdepartment Radio Advisory Committee (IRAC), have long sought to keep Government usage of the spectrum as efficient as both economic and mission requirements would permit. In 1992, completing a two year effort, NTIA halved channel widths in the 162-174 MHz band, the band most heavily used for Federal non-military land mobile communications. This change accommodates expanding requirements of all agencies in this band by almost doubling the number of available channels. Also in 1992, NTIA working with the FCC converted the 220-222 MHz band from the radiolocation service to the mobile service for Federal and non-Federal narrow-band land mobile use. In addition, eight years ago NTIA urged industry to develop and market trunking communication systems in the bands available to Government users and urged the FCC to revise regulations that prohibited Government agencies from using commercially offered specialized mobile radio services.

Mobile systems provide communications between mobile stations and land stations or between two or more mobile stations. The mobile services include aeronautical, maritime, and land mobile services. The aeronautical and maritime mobile services must meet national standards, as well as the technical and interoperability standards that are established by international organizations. Domestically, the frequencies and operations are established through Federal Government and FCC (non-Federal Government) regulations. Because of these international standards NTIA cannot unilaterally implement spectrum efficiency standards for the aeronautical mobile, maritime mobile, and mobile-satellite services. Actions are now under consideration internationally to make the aeronautical and maritime mobile services more spectrally efficient. NTIA and the Federal agencies are working cooperatively with the FCC and international bodies to establish spectrum efficiency standards for these services.

The Department of Defense operates a large number of tactical and training mobile radio systems whose functions are directly tied to the defense of the United States. These systems have no civilian counterpart, have specialized functions, and support some very complex missions. Currently, military standards define the specialized technical characteristics required for some military equipment. In the future, the military services plan to purchase more equipment from commercial vendors (i.e., off-the-shelf) thereby eliminating some of the need for procurement of equipment built to specialized military standards. Further details on the

requirements and architectures used by the aeronautical mobile, maritime mobile, and defense tactical systems are included in Section 3.

Based on the unique situations for aeronautical mobile, maritime mobile, and defense tactical and training mobile systems described above, the approach used in this report was to identify an implementation plan only for land mobile systems, excluding defense tactical and training systems. The plan is for land mobile system operation above 30 MHz. Mobile systems operating below 30 MHz are characterized by signals which are often propagated great distances by ionospheric reflection. Additionally, there are a myriad of different system types below 30 MHz used for a variety of unique purposes.

NTIA released a Notice of Inquiry (NOI) on June 12, 1992 entitled "Current and Future Requirements for the Use of Radio Frequencies in the United States."[2] The purpose of the NOI was to collect information on national spectrum requirements and technology trends as part of a national, long-range spectrum planning effort. Comments were requested from both the private sector and Federal Government agencies. NTIA will issue a report on national spectrum requirements and technologies based on these NOI comments and inputs received from a seminar held on the subject. This information and its analysis will be the basis for more effective long-range national spectrum planning for all services including the aeronautical mobile, maritime mobile, and defense-related services described previously. Excerpts from the comments are included in numerous places within this report.

In July 1991, the FCC released a Notice of Inquiry (NOI) that sought information on any new technical, operational, or regulatory techniques that could be used to promote more efficient use of the private land mobile radio (PLMR) bands below 512 MHz. The FCC used the NOI and the comments it generated to draft a Notice of Proposed Rule Making (NPRM) consisting of policy-change proposals designed to increase channel capacity and to encourage use of spectrum efficient technologies. This process of developing new band-use policies is called "refarming of the spectrum", or simply "refarming."

NPRM proposals that are relevant to the objectives of this report include plans to reduce channel spacing and emission masks, to provide for channel exclusivity below 470 MHz, to reduce maximum allowable power levels and antenna heights, to designate

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[2] National Telecommunications and Information Administration, U.S. Department of Commerce, *Current and Future Requirements for the Use of Radio Frequencies in the United States*, Notice Of Inquiry, Doc # 920532-2132.

channels for innovative shared use operations, to designate channels for nationwide operations, and to allow trunking in bands below 800 MHz.

OBJECTIVES

The development of a plan was mandated by Congress in the NTIAOA. This development continues the earlier NTIA efforts and will help relieve demands by Federal Government agencies for more spectrum to expand existing types of service. The objectives of the plan are to:

- ensure that Federal agencies retain access to all land mobile technologies and services required to adequately support their missions.

- ensure that Federal agencies use spectrum-efficient radio technologies to satisfy their communication requirements, while seeking to minimize both the amount of spectrum used and the associated long-term costs.

- ensure that Federal agencies use commercial sources or shared, interagency and intra-agency systems to provide land mobile radiocommunication services unless services or systems that can meet telecommunication mission requirements are not available or the available services or systems would cost more than alternatives.

APPROACH

A working group of the IRAC, an interagency advisory group, advised NTIA in the preparation of the plan. In particular, the Federal agencies drafted much of the input for Section 3 pertaining to Federal Government mobile requirements. NTIA also reviewed the FCC NPRM on "refarming" and the comments from participants at FCC refarming seminars.[3,4,5] The

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[3] Federal Communications Commission, Notice of Proposed Rule Making, PR Docket No. 92-235, November, 1992.

[4] *FCC Refarming Panel Discussion*, FCC Headquarters, Washington, DC, March 1, 1993.

[5] *FCC Refarming Technical Roundtable*, FCC Headquarters, Washington, DC, May 6, 1993.

development of the plan was completed within the Federal Government sector exclusive of FCC participation or review.

The findings and recommendations of this effort are contained in Section 2 which also includes an implementation milestone time plan. Section 3 is a review of Federal Government mobile requirements and techniques. Section 4 identifies current and evolving technologies which, when implemented, will improve spectrum efficiency. Section 4 also defines measures that can promote cost effectiveness.

Section 5 is a comprehensive presentation of the suggested plan elements that relate to implementation of Federal technical and operational standards. Section 6 is a discussion of policy issues regarding proposed new regulatory and processing methods introduced to assist Federal Government agencies in the use of more spectrum-efficient technologies.

SECTION 2
FINDINGS AND RECOMMENDATIONS

FINDINGS

The analysis contained in this report reviewed existing Federal Government use of the spectrum for mobile services, the status of technology used to provide mobile communications, and existing NTIA and other agency policies regarding mobile services. Current NTIA regulations and other Government regulations concerning acquisition of telecommunication resources were investigated to determine appropriate types of regulation for Federal land mobile communication services and to keep NTIA regulations from conflicting with them.[6]

Along with this report, a summary of the plan presented at the end of this section was prepared for Congress as required by the NTIAOA. This summary report, entitled **LAND MOBILE SPECTRUM EFFICIENCY REPORT:** *Summary Report,* was coordinated with NTIA, Department of Commerce and Congressional senior staff members, whose comments led to several clarifications and amplifications. The *Summary Report* contains descriptions of NTIA's planned policies and procedures, which have been expanded beyond those provided here. The milestones in both plans are the same. The *Summary Report*, an enclosure to the letters sent to Congress, is the Land Mobile Spectrum Efficiency Plan to be implemented by NTIA.

This report reaches several findings and recommendations regarding how NTIA could continue to expand its efforts to ensure that Government usage of the spectrum allocated to mobile services is as efficient as both economic and mission requirements permit. Several of these would increase the number of channels available to the Government for land mobile communications without increasing the amount of spectrum dedicated to that use. Others would increase the number of users that can operate on each communication channel. In addition, the policies and procedures used by NTIA for managing Federal Government use of land mobile radiocommunication services have also been reviewed. Provisions that will continue to encourage introduction of more spectrum-efficient technologies and methods have been recommended. The findings reached are:

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[6] Other regulations reviewed include Office of Management and Budget regulations concerning commercial activities in *OMB Circular No. A-76* and General Services Administration regulations concerning the management of Federal information resources in the *Federal Information Resources Management Regulations*, see 41 C.F.R. § 201.

• The rapid growth in the demand for land mobile services is reflected in the doubling of Federal land mobile frequency assignments between 1980 and 1992.

• Federal mission requirements often lead to local, national and worldwide service areas that include remote, rural, suburban, and urban environments. Missions mandated by the Congress and the President have few counterparts outside the Federal Government, although State and local government missions and corresponding uses of the radio spectrum in support of these missions are similar in many ways.

• Federal land mobile radio systems use a wide range of equipment types in a variety of geographic environments for voice and data communications. Common types of equipment include base and repeater stations, mobile stations, and hand-held, portable stations. This equipment is, generally, the same "off-the-shelf" analog FM equipment used outside the Government, operating on different frequencies. Since the technology is the same, the spectrum-efficiency and cost-effectiveness of the radio technologies used by the Federal Government are usually identical to that used in readily available commercial radio systems.

• NTIA has selected a 12.5 kHz channel width for rechanneling, which will double the number of channels available and can be accomplished using currently available technology. Federal agencies have already begun procurement of these new radios for the 162-174 MHz and 406.1-420 MHz bands. In addition, 12.5 kHz radios are expected to be adopted by Federal, State and local law enforcement agencies to ensure baseline interoperability. If the FCC chooses a different channel width (*e.g.,* 6.25 kHz or 5 kHz) as a consequence of their refarming initiative, NTIA will evaluate the impact of this decision on Government operations, spectrum efficiency and cost considerations.

• Under certain conditions trunking systems are more efficient than conventional systems. When there are a large number of users with a high volume of short duration messages, a trunking system can significantly increase total traffic throughput on individual communication channels and still provide a high probability of immediate access to users. Agencies with large numbers of users spread throughout a campus-like geographic area have found trunking systems to be especially useful. Wide area systems, which allow users to roam over large areas, such as a state or several counties, or between several areas are being implemented.

• Land mobile systems operated by commercial vendors offering services on a for-fee-basis to all Government agencies and systems jointly owned and operated by the user agencies are being successfully implemented. NTIA is conducting two pilot programs with commercial

vendors to investigate the feasibility of using land mobile systems constructed at no cost to the Government to satisfy Government land mobile requirements. Despite some implementation difficulties, one of the pilot programs is nearing operational success. The second, and more ambitious, is too early in its implementation phase to properly evaluate. In neither case do applicable regulations or procedures exist and NTIA is assuming active oversight to ensure that the pilot systems are effectively used.

- Although Federal agencies are making growing use of cellular telephones, they have expressed several concerns, which have restricted their use of these and other commercial communication services. Their concerns include: the Federal Government does not own the infrastructure, the systems do not operate on Government frequencies, the systems may be overloaded and Government agencies may be locked out and unable to gain priority access, and the communication can be easily intercepted. Another concern is the recurring cost associated with cellular systems.

- Government plans are currently being formulated by the potential user agencies to use commercial Personal Communication Services (PCS) to supplement the Federal mobile service infrastructure. The Government expects to use and own unlicensed PCS devices, such as, wireless Private Branch Exchanges (PBX) and wireless Local Area Networks (LANs). The Government also expects to obtain Cellular Radio and PCS services, as well as other services extending the public switched telephone network to mobile users, from commercial service providers.

- There are provisions in the current NTIA and FCC regulations for sharing of frequencies between Federal, State and local users for coordinating law enforcement and emergency operations that have been developed over many years, and are generally satisfactory for these purposes. However, the use of shared Federal, State, and local government trunking systems would facilitate the close cooperation needed between police and emergency assistance personnel under some circumstances and allow the economic expansion of large wide area land mobile communication systems needed by all three levels of government.

RECOMMENDATIONS

Agency Operated Government Land Mobile Systems

- In order to fulfill its mandates to "promote efficient and cost effective use of the spectrum to the maximum extent possible" and develop a "plan for Federal agencies . . . to use . . . technologies that are at least as spectrum-efficient and cost-effective as readily available commercial" land mobile radio systems, while minimizing long term costs and ensuring that agency mission requirements are satisfied, NTIA should implement policies that:

  - authorize agencies to operate their own land mobile systems where:

    - land mobile services offered by commercial vendors, including Specialized Mobile Radio (SMR) and other trunking systems, cellular radio systems, and "Personal Communication Services," are not available; or the use of such services would not meet requirements, would cause unacceptable delay or disruption, or would cost more;

    - shared land mobile services offered by other agencies are not available; or the use of such services would not meet requirements, would cause unacceptable delay or disruption, or would cost more; and,

    - land mobile services offered by State and local governments are not available; or the use of such services would not meet requirements, would cause unacceptable delay or disruption, or would cost more.

  - require the use of spectrum-efficient and cost-effective technologies to meet mission requirements where commercial services and services obtained from other agencies cannot be used.

  - withhold frequency assignments for Government land mobile radio stations that do not meet the goal of making efficient and cost-effective use of the spectrum.

Commercially Operated Government Land Mobile Systems

NTIA should review regularly, with the IRAC, the results of current experiments and revise as necessary policies and procedures that permit commercial vendors access to Federal spectrum to provide land mobile services to the Federal Government.

Recommended Milestones

1. Release the **LAND MOBILE SPECTRUM EFFICIENCY PLAN** . . . . . 1 Oct 93

   a. Publish details of the implementation of the **LAND MOBILE SPECTRUM EFFICIENCY PLAN** in the *Federal Register* for public review . . . . . 1 Dec 93

2. Procedures for continuing Federal use of spectrum-efficient land mobile technologies.

   a. Implement procedures requiring each agency to consider spectrum-efficient alternatives, including commercial service alternatives for land mobile systems . . . . . 1 Oct 94

      (1) Develop initial draft regulations and task the IRAC with development of proposed changes to the NTIA Manual . . . . . 1 Nov 93

      (2) Completion of draft changes to the NTIA Manual . . . . . 1 Apr 94

      (3) Publish summary of proposed changes to the NTIA Manual in the *Federal Register* for public comment . . . . . 1 May 94

      (4) Receive public comments on proposed changes to the NTIA Manual . . . . . 15 Jun 94

      (5) Receive reply comments . . . . . 15 Jul 94

      (6) Complete revisions to the NTIA Manual based upon public comment and advice received from the IRAC . . . . . 1 Sep 94

      (7) Publish decision in the *Federal Register* . . . . . 1 Oct 94

   b. Review the degree of success and any implementation problems associated with the two NTIA pilot programs involving commercial vendors. . . . . 1 Feb 95

(1) Discuss the degree of success and any implementation problems with the IRAC . . . . . 1 Mar 94
(2) Draft needed policies for expansion of services offered by commercial vendors on a fee-for-service basis to Government agencies and task the IRAC with development of implementing regulations and procedures . . . . . 1 Apr 94
(3) IRAC complete revisions to the NTIA Manual implementing these procedures based upon comments from the public and advice received from the IRAC . . . . . 1 Jul 94
(4) Publish proposed revisions to the NTIA Manual in the *Federal Register* . . . . . 1 Aug 94
(5) Receive public comments on proposed changes to the NTIA Manual . . . . . 1 Oct 94
(6) Receive reply comments . . . . . 1 Nov 94
(7) Complete revisions to the NTIA Manual based upon public comments and advice received from the IRAC . . . . . 1 Jan 95
(8) Publish decision in the *Federal Register* . . . . . 1 Feb 95

3. Channeling Plans

NTIA will ensure that the Federal Government frequency bands used for land mobile applications are rechanneled to narrower bandwidths and provisions are made to accommodate digital modulation systems with equal or greater efficiency. In addition, procedures for fully implementing current provisions for sharing of public safety service land mobile radio channels between Federal, and State and local government users will be developed and needs for expansion of this type of sharing will be continually examined.

The 162-174 MHz band was rechanneled to 12.5 kHz channels in 1992, and the procedures are currently being implemented. The 406.1-420 MHz and 138-150.8 MHz bands will be rechanneled using the following schedule, and all land mobile bands will be reviewed periodically thereafter.

a. The 406.1-420 MHz band
(1) Rechannel to a 12.5 kHz channel width . . . . . 31 Dec 93
(a) New systems must use the new 12.5 kHz channels . . . . . 1 Jan 95
(b) Convert all systems . . . . . 1 Jan 2008

(2) Evaluate as necessary, with the IRAC, plans to encourage efficient use of the spectrum in this band . . . . . 30 Sep 94
(3) Publish proposed changes to the NTIA Manual in the *Federal Register* for comment . . . . . 1 Dec 94
(4) Complete revisions to the NTIA Manual implementing these procedures based upon comments from the public and advice received from the IRAC . . . . . 1 Feb 95
(5) Publish decision in the *Federal Register* . . . . . 1 Mar 95

b. The 138-150.8 MHz band

(1) Rechannel land mobile portions of this band to a 12.5 kHz channel width . . . . . 31 Dec 94
(a) New systems must use the new 12.5 kHz channels . . . . . 1 Jan 98
(b) Convert all systems . . . . . 1 Jan 2008
(2) Create, with the IRAC, a channeling plan and electromagnetic compatibility standards to encourage efficient use of the spectrum for both trunking and conventional land mobile systems . . . . . 30 Sep 94
(3) Publish proposed changes to the NTIA Manual in the *Federal Register* for comment . . . . . 1 Dec 94
(4) Complete revisions to the NTIA Manual implementing these procedures based upon comments from the public and advice received from the IRAC . . . . . 1 Feb 95
(5) Publish decision in the *Federal Register* . . . . . 1 Mar 95

4. Increased Government Sharing

Evaluate existing rules and procedures and develop new ones where necessary to implement current provisions for sharing between Federal, State and local government users . . . . . 31 Dec 94

SECTION 3
FEDERAL GOVERNMENT MOBILE RADIO REQUIREMENTS AND TECHNIQUES

FEDERAL GOVERNMENT MOBILE RADIO REQUIREMENTS

Introduction

Federal Government land mobile communication requirements are accommodated in segments of the following bands which are allocated to the fixed and mobile services for non-tactical use: 30-50, 138-144, 148-149.9, 150.05-150.8, 162.0125-174, 220-222, and 406.1-420 MHz. Federal Government agencies use the fixed and mobile radio systems that operate in these bands to accomplish a variety of missions that serve the public.

Federal mobile radio systems use a wide range of equipment types in a variety of geographic environments for voice and data communications. Common types of equipment include base and repeater stations, mobile stations, and hand-held portable stations. In nearly all cases, this equipment is the same type of "off-the-shelf" equipment used by local and State public safety agencies.

Mission requirements often lead to worldwide and nationwide, as well as local service areas that range in character from remote to urban. Federal Government missions are mandated by Congress and the President, and generally have no counterparts outside the Government. The closest are the State and local governments with similar missions that own and operate their own systems. The major differences lie in two areas: (1) the national security operations of the Federal Government, and (2) the geographic areas of communication coverage required.

Federal Government radio systems support agency mission requirements in the following broad categories: law enforcement, transportation, natural resources, emergency and disaster services, utilities, medical, and administrative. Federal Government radio systems are usually multi-purpose systems; e.g., law enforcement, natural resource, medical, administration, and utility functions may be supported on the same radio system; thus increasing their spectrum efficiency. Federal Government land mobile requirements for each of the above categories are described in the following subsections.

Law Enforcement

Federal law enforcement radiocommunications requirements include everything from hand-held portable communications between internal security posts to nationwide/worldwide airborne communications for drug interdiction and protection of the President. Federal law enforcement radiocommunications must be immediate; delay is not acceptable.

Effective and reliable radiocommunications are required for safety-of-life and property protection of Federal building complexes, Federal lands, military bases, and other types of installations. A major use of dedicated radiocommunications is the security of current and former Presidents and family members, as well as the Vice President and family, and other distinguished persons including foreign heads of state.

Operations requiring high priority communications include movement of protected individuals, in response to violent crimes (bank robbery or kidnapping), undercover surveillance, and arrests. Cases involving counterintelligence, personal crimes, organized crimes, drug interdiction, fugitives, hostage situations, terrorism, smuggling, guns and explosives, counterfeiting, fraud, forgery and tax evasion also require immediate communications. Additionally, portable radios and body transmitters are used inside prisons for prisoner control activities, and by special agents to support investigative functions, and in personnel and property security operations.

Most Federal law enforcement agencies have area offices that are responsible for activities throughout a geographic region. Repeaters and radio links are installed to obtain the necessary radiocommunications coverage within that region. Repeater systems are installed throughout urban areas in these regions to permit necessary portable radiocommunications. Transportable equipment is provided to respond to impromptu travel requirements in support of personnel protection or pursuit of criminal cases, special cases, or other major crises such as Waco, Texas, and the bombing of the New York City World Trade Center in early 1993.

Federal law enforcement systems require communications with privacy. The monitoring of clear voice communications by the general public, the news media, foreign intelligence agents, and criminals has disrupted investigations and caused life-threatening situations for law enforcement personnel and innocent victims. Digital encryption, spread spectrum and other techniques are now utilized to assure transmissions are not compromised.

Installation of radio systems that provide complete coverage of the United States is not spectrum-efficient. However, the mandated missions of Federal law enforcement agencies require the capability to deploy and install both permanent and temporary facilities when and wherever needed, not only nationwide but worldwide. This is accomplished through agency-dedicated means, including full and complete control of installations, operations, and maintenance by the various elements of the law enforcement community.

Transportation

Federal activities in aviation, maritime, highways, and railroads have a heavy investment in both fixed and land mobile operations. Aviation-sector land mobile applications include maintenance, safety, and inspection using portable and mobile radios, and repeaters and base station facilities; remote maintenance monitoring equipment; remote control of robot devices at supply depots; airport runway light control systems and windshear alert systems. These systems are installed in airports and airway facilities for management and coordination activities. The systems use both voice and data to: automate equipment monitoring; perform safety-of-life, anti-terrorist, and air security functions; integrate air traffic control communications within the centers and control towers; and conduct various airport and airfield communications as necessary, tailored to the needs of each airport/airway location.

Federal maritime management coordination, safety, and law enforcement activities also use radios operating in Federal land mobile bands. These activities require nationwide implementation, although many operations are concentrated in seaports, docks, and waterways of the nation's coastal areas, major rivers, and the Great Lakes region.

Federal surface transportation operations provide a variety of management and oversight support to coordinate activities at various highway and rail sites. Many of these functions are mandated by law and nationwide in scope.

Natural Resources

The Federal Government manages its natural resource programs using radiocommunications to accomplish Congressionally-mandated missions. Fixed stations, mobiles, handheld portables, and transportable repeaters and base stations make up these radio systems. These operations are spread throughout the United States and Possessions,

in suburban, urban and rural sometimes remote and almost inaccessible areas. Some systems encompass only a few buildings in a city or a small wildlife refuge. Others encompass large geographical areas, such as, the national forests, Indian reservations, and national parks; multiple counties or states, such as the Tennessee Valley Authority; or are nationwide in nature.

These systems provide for the safety of the public and Government personnel; monitoring and distribution of water; management of timber growth and harvest; protection, operation, and management of our national parks, national forests, range and grass lands, wildlife refuges; protection and management of wildlife and fisheries; recreation; surveying and mapping; protection of Native Americans and protection and management of their lands; forestry and range management; and assessment of mineral deposits. Wildlife monitoring and tracking to protect endangered and threatened species and to control animal damage are performed in these bands with transmitters as small as dimes or as large as softballs.

Emergency situations such as fires, hurricanes, earthquakes, volcanic eruptions, etc., place great demands on the existing communication systems each year and routinely require the use of emergency backup systems. These emergencies sometimes require a tenfold expansion of communications facilities in a matter of hours. This separate function is described in greater depth in the next section.

Emergency and Disaster Services

The Federal Government provides an array of emergency and disaster response communications capabilities to protect the American public and resources from natural disasters and technological hazards. This involves a wide range of missions including prevention, mitigation, preparedness, response and recovery. These services involve virtually every department and agency of the government. Where safety of life and property is at risk, communication systems that can operate reliably even when normal systems are disrupted are essential. Spectrum-dependent emergency radio systems are the only systems capable of providing the essential levels of reliability, mobility, and flexibility during crises. A significant number of the Federal Government emergency and disaster response communications systems interface with State and local governments as well as with national volunteer organizations such as the Red Cross, amateur radio operators and similar groups. An important consideration in managing these emergency assets is the need to conduct periodic exercises to ensure they work when required.

Many specialized emergency requirements have unique spectrum-dependent needs that must also be satisfied by the nationwide dedication of radio spectrum for that purpose. As an example, Federal, State, and local government search and rescue teams deploying to the site of a national emergency or disaster need reliable communications to locate victims in collapsed buildings, administer medical and lifesaving treatment and relocate them to safety or medical facilities.

Providing the communications needed during major natural and technological emergencies requires a significant quantity of readily deployable land mobile radiocommunications. Major natural disasters occur on a continuing basis. Major disasters, such as Hurricanes Andrew and Hugo, the San Francisco earthquake, and the recent floods in the Mississippi Valley have required the deployment of thousands of radios. These have been Federal Government-owned land mobile radios used to effectively coordinate and provide emergency management during the readiness, response and recovery phases of major natural and manmade disasters. Land mobile radios are critical for providing the needed level of flexibility and survivability required. Dedicated, reliable non-blocked resources are required to support these time-sensitive, high demand operations to improve rapid response, to minimize interference, and to safeguard emergency response personnel and the delivery of life saving services to the general public.

Utilities

Federal Government utility operations which provide essential services to both Federal Government and non-government users are also supported in these bands. These operations include generation of electric power at fossil, hydro, and nuclear power plants; the distribution of electrical energy and the maintenance of distribution lines; and the distribution of potable and agricultural waters and the maintenance of these systems.

The distribution of electrical energy from the generating plants to the load centers and the interconnection of bulk electrical power supply systems for reliability and adequacy has required the development of complex, supportive radio systems. Communications must be of the highest level of reliability, economically and technically feasible, and must be instantly available for the successful operation of these electrical power systems.

Radiocommunications systems are also vital to the operation and maintenance of water distribution and sewage systems on military bases, water distribution systems encompassing

aqueducts and canals in arid areas, and dams for the control of flooding. Radio systems provide for collection of water flow and salinity data and control of irrigation ditch gates and pumping stations for the management of vast water distribution systems and the maintenance of these systems. Dam safety data is transmitted to central processing points to provide early warning of potential dangers and scheduling of maintenance. Day-to-day operations of these systems with limited field personnel resources provide for efficient and timely response to changing customer requirements.

The criticality coupled with the remote areas encompassed by many of these systems have generally precluded the availability of cost effective support from commercial communications providers.

Medical

The Federal Government provides essential land mobile radiocommunications for medical facilities. Reliable radiocommunications are required to provide life-or-death medical care along with the daily operations of a medical center. Radio paging communications are essential to obtain doctors and nurses during emergency situations. Two-way radiocommunications are required to interact with local governments to provide security, fire protection and maintenance. Reliable radiocommunications are required for local, Federal Government, civilian, and military medical facilities to interact with each other to provide essential emergency medical care.

Administrative

"Administrative" communications is the descriptive term for various support type communications used for administrative management of personnel or material required in performing Federal Government missions. All Federal Government agencies employ some type of administrative land mobile communications systems within their respective departments. Examples of these support communication systems include base stations for VIP management and control of operations and test-range safety, wireless microphones, maintenance communications, motorpool, building guards, and paging. These systems use fixed and transportable base stations and repeaters, mobiles and handheld portables.

NON-FEDERAL AND FIXED USES

The bands that accommodate Federal Government land mobile communications also support a number of non-government uses, including:

Public Safety services
Hydrologic data collection systems
Cordless telephones
Wireless microphones
State and local government forestry fire fighting and conservation operations
Radio astronomy observations
Remote pickup broadcast operations
Medical radiocommunications
Maritime mobile public correspondence
Police radio service stolen vehicle recovery systems

The Federal Government fixed uses in these bands include the collection of seismic, meteorological, and hydrologic data for the forecast of volcanic eruptions and earthquakes; identification of potential fire danger areas; and prediction of availability of water for agricultural and public use. These data are provided to State and local officials for planning and emergency operation purposes. National Oceanic and Atmospheric Administration (NOAA) Weather Radio, which provides the public with up-to-date weather information, also operates in the 162-174 MHz band.

FEDERAL GOVERNMENT MOBILE TECHNIQUES

The Federal Government may use one or more of the mobile system techniques listed in TABLE 1.

TABLE 1
MOBILE TECHNIQUES

simplex
repeaters
trunking, SMR
transportable
cellular
emerging wireless technologies
digital mobile data
aeronautical mobile
maritime mobile
defense tactical

The operational requirements as discussed in the previous section, the volume of mobile traffic for individual applications, and cost considerations, dictate which mobile technique is used. Federal mobile service operations, other than paging, are usually point-to-point two-way communications between a base and mobile station or between two mobile stations. Additionally, Federal users communicate in a dispatch/supervisory mode (one-to-many) or communicate one-to-one while the other users listen-in and take action as appropriate. Many types of mobile equipment are used such as fixed and transportable base and repeater stations, and mobile and handheld portable stations. The Federal Government makes extensive use of transportable systems which often must be rapidly deployed. Transportable systems are designed so that all system components (base as well as mobile stations) can be easily redeployed to a different area.

Typical communications messages from mobile sources are relatively short in time. For example, a conversation that starts with a question from the base station and ends with a reply from the mobile represents two separate communications segments. Typical channel hold times for Federal Government mobile communications are quite short and usually last less than a minute. Spectrum efficiency considerations would therefore dictate that mobile system users share the communications channels.

Channels can be shared by multiple users, for example, if users monitor the status of the channel and transmit only when the channel is unoccupied. An alternative is to utilize automatic processing to keep track of the channels and to assign channels based on real-time

requests from users. Mobile systems that use several channels with automatic frequency selection are called trunked systems. The advent of automated processing has made it possible for a "computer" to keep track of several channels (e.g., 3, 5, 10) and to automatically assign channels to users as they are requested. When all channels are occupied, a queue is established to provide channels for waiting users as channels become available.

Each of the mobile techniques in TABLE 1 is described below. The more complex techniques such as trunking, cellular, digital data, and emerging wireless technologies require significant automatic processing. Processing adds expense but also adds additional capabilities and may improve spectrum efficiency. In some situations, the most spectrally efficient and cost-effective systems are of the simplest design.

Simplex Mobile Service

The NTIA Manual definition of simplex operation allows for both single-frequency and two-frequency implementation.[7] The terms simplex and duplex are somewhat ambiguous since there are numerous definitions for these terms. If a mobile system is a single-frequency simplex system, the mobile stations and the base station transmit on a single, shared frequency. If it is a two-frequency simplex system, it uses a different frequency for transmitting and receiving. Two-frequency simplex systems generally involve a repeater. Both types of simplex systems require the typical "push-to-talk" operation, in which each station can listen or transmit, but cannot do both simultaneously. In a full-duplex system, a pair of frequencies is also used, but each station can simultaneously listen on one frequency while transmitting on the other, i.e., cellular telephones. Most non-cellular Federal Government mobile radio systems operate in single or two-frequency simplex modes.

Simplex mobile service systems are the technically simplest type of dispatch systems and were the first type of system to gain widespread use. The most basic simplex system consists of a single base station that communicates simultaneously with all mobile units in its

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[7] National Telecommunications and Information Admin., U.S. Department of Commerce, *Manual of Regulations and Procedures for Federal Radio Frequency Management*, May 1992 ed., rev. through September 1992, (NTIA Manual) p. 6-13. The NTIA Manual is the principal document for Federal Government spectrum management policies, rules, and technical standards. NTIA maintains the NTIA Manual with the advice of the Federal Government agencies and issues revisions several times a year. The NTIA Manual and all changes are incorporated by reference in 47 C.F.R. §300.1.

coverage area without the use of repeaters or automated frequency selection techniques. Federal Government applications use simplex mobile systems for mobile-to-base, and two-frequency simplex systems for mobile-to-base and mobile-to-mobile communications. A diagram of a one-frequency non-repeater simplex mobile system is shown in Figure 1.

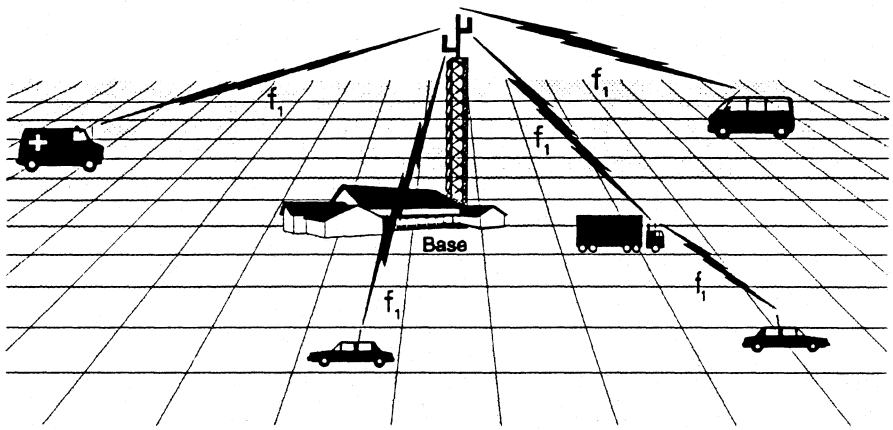

Figure 1. One-frequency non-repeater simplex mobile system.

For conventional systems, each organization with communications requirements obtains a frequency, or pair of frequencies for two-frequency simplex systems, and builds a complete system using these frequencies. If communications are needed over a large area with a 50 kilometer radius, for example, the users typically operate one or more base stations with towers elevating the antennas.

Simplex mobile units generally are limited to small antennas and low transmitter power because of vehicle mounting problems. "Walkie-talkies" (portable, hand-held units) are even more seriously constrained in antenna design and transmitter power (typically 1-3 watts). Because of the need for two-way communications in most situations, the performance of the portable transmitting units is the weak link that limits the communications range. In fringe locations, the portable unit may be able to hear the more powerful base station transmitter, even though the base station cannot hear the weaker portable signal. The useful range between portable units is relatively short.

A single base station typically transmits to many mobile/portable units. In a simple system, all users hear the messages broadcast from the base station, even though the

message may be intended for only one of those users. To eliminate the distraction and inconvenience on the part of the unintended listeners, some systems transmit a tone or signal containing the identification of the intended listener. Although all mobile units receive the message, the loudspeaker is activated only on the intended receiver and only the intended listener hears the message. In some applications, of course, it is desirable for all users to hear all transmissions so that they can remain completely aware of the progress of the activity that is underway. In other applications, it is possible that only a subgroup of the users needs to be made aware of the activity on a particular project.

Repeater and Mobile-to-Mobile Systems

Repeaters help solve the problem of limited range. A problem users often face in establishing their own system is that their business office location is not a good site for a base station transmitter. It might be in an office complex that does not permit tall antenna towers, or in a valley that severely limits the radio coverage range, even if a tall tower could be built at that location. What the user really needs for good coverage is to put a repeater on top of a tall building or on top of a convenient, nearby mountain and use a radio link to connect the office location with the repeater.

Communications between the office and mobile units through a repeater take place in two stages in each direction (See Figure 2). The office transmits to the repeater on frequency *A*. The repeater then retransmits the signal to the mobile units on frequency *B*. The mobile unit that replies also transmits to the repeater on *A*. The repeater then re-transmits the reply to the office on *B*.

Several important features of this process should be noted. The repeater handles signals from the office and mobile units identically. It does not need to know whether it is receiving a signal from the office or from a mobile unit. The repeater does not originate signals; it simply receives any signal on *A* and repeats (retransmits) it on *B*. Functionally, the office station is identical to the mobile units, and may operate with the same type of transmitter power and antennas as the mobile units. Communications between two mobile units is limited only by the requirement that both units be within radio line-of-sight of the repeater.

In some repeater systems a mobile may also have the ability to communicate directly with another mobile in a mobile-to-mobile or "talkaround" mode (See Figure 2). To operate in

this mode the mobile user first selects the channel set aside for mobile-to-mobile operation (usually the repeater transmit frequency). To return to repeater mode, the mobile unit simply switches to the repeater receiver channel.

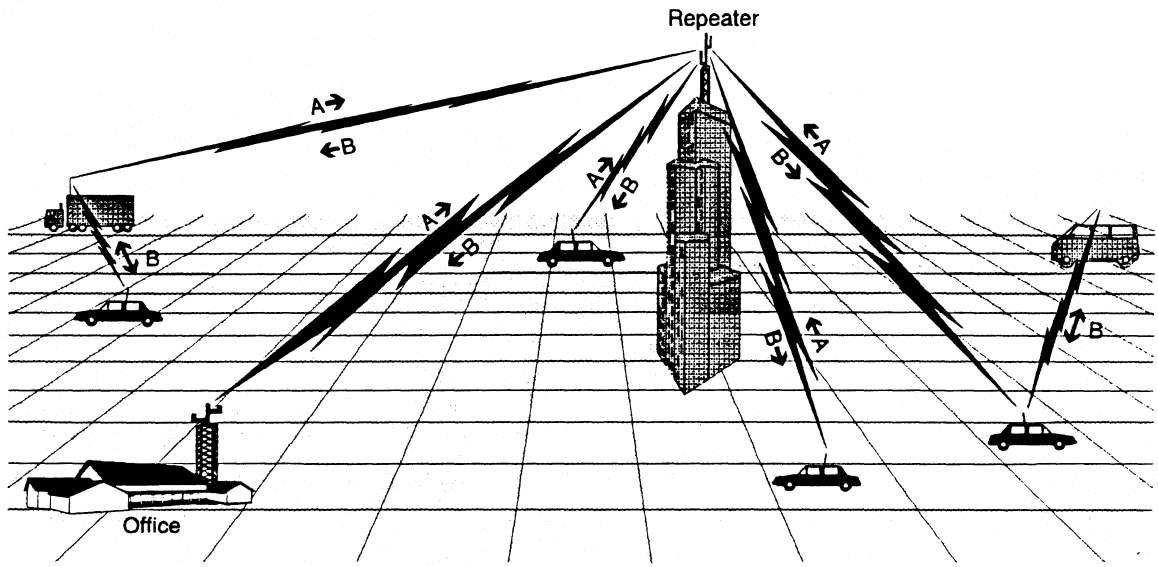

Figure 2. Repeater system with mobile-to-mobile capability.

Dedicated land mobile systems implemented for specific buildings are sometimes used within Federal buildings to provide communications between security, maintenance, and other personnel. A typical in-building radio system architecture includes a repeater on top of the building plus leaky coaxial cable in some interior building locations, when necessary.

Trunking and Specialized Mobile Radio (SMR)

Federal mobile radio users often need to push a button and commence communication immediately. Trunking supports this requirement through its ability to automatically monitor and assign available channels. A technical explanation of how trunking satisfies this immediate communication requirement is given in Section 4. One method of trunking is shown in Figure 3. Trunking is becoming increasingly important for this and other value-added functions within the Federal Government.

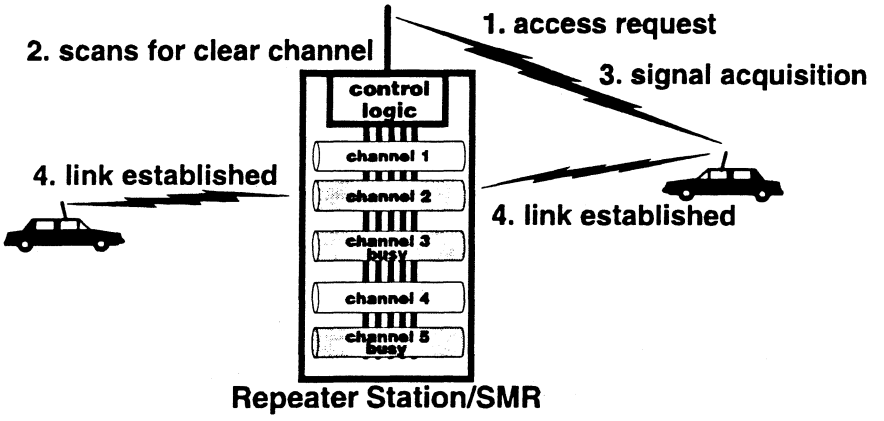

Figure 3. The trunking/SMR concept.

Trunking systems can be categorized by loading (number of mobiles), number of channels, architecture (e.g., simulcast, etc.) and service area. Typical service areas for trunking systems include:

In-Building. Typical implementations may use an antenna situated on top of the building, or leaky radiating cables with bidirectional amplifiers. The most common form of mobile radio used inside a building is the hand-held portable.

Campus. In this application, communication can be provided among users in a limited geographical area. One advantage of a trunking system is that "talk groups" such as the motor pool can communicate with other "talk groups" such as the supply department when necessary. Mobile terminals may be in vehicles or hand-held portables. A number of Federal agencies are establishing campus trunking systems.

City and Regional. A trunking system can provide communications for a city. Several existing trunking systems can be combined into a network to provide regional coverage. It is also possible to design a regional system from the start. A regional system that uses simultaneous transmissions of the same message on the same frequency from different antennas throughout a large area is called a

simulcast trunking system. This type of system is spectrally efficient and its use is encouraged.

TABLE 2 lists the number of approved Federal trunking systems by Federal agency.

TABLE 2
CERTIFIED FEDERAL TRUNKING SYSTEMS[a]

Agency	Number of Certified Systems[b]
Air Force	16
Army	19
Commerce	1
Energy	8
Health and Human Services	2
Justice	13
Navy	17
NASA	8
USPS	1
TOTAL	85

[a] As of July 1,1993
[b] Only those systems established after November 29, 1969.

Four groups of channel-pairs (five pairs per group) in the 406.1-420 MHz band are designated for, but not limited to, trunking systems. By NTIA regulation, trunked land mobile systems are also encouraged and may be established in any exclusive Federal frequency bands allocated for fixed and mobile operations.[8]

Although trunked land mobile radio systems may be established in any exclusive Federal frequency band allocated for fixed and mobile operations, a specific trunking plan for the 406.1-420 MHz band is provided in the NTIA Manual. Several multi-agency Federal

[8] Ibid, Sections 2.3.10 and 8.2.48.

committees are currently evaluating existing rules and procedures for Federal Government use of trunked systems.

In 1988, NTIA approached the Department of Commerce's Office of Procurement with regard to the concept of letting a solicitation for the private sector to build and operate trunked radio systems in the Government 406.1 - 420 MHz band. The award (to Motorola, GOSMR) is referred to as an initial pilot trunking system and Washington, DC was selected as the geographic site. The system began operation in June of 1991 and uses five frequency pairs.

A second solicitation was released by the Department of Commerce's Office of Procurement in November 1991. Proposals were requested to build and operate 5-channel trunking systems at no initial cost to the Federal Government for areas outside of Washington, DC. In December 1992 a private corporation, FEDSMR, was awarded the contract to build and operate trunked radio systems in Boston, New York City, Philadelphia, Baltimore, and Norfolk. The systems are planned to become operational in early 1994.

The FCC grants Specialized Mobile Radio (SMR) licenses to entrepreneurs to construct and operate commercial/non-Federal Government trunking systems. The operation of these systems is in the Specialized Mobile Radio (SMR) Service. Typical users of the services are construction, transportation, and service-oriented users.

Federal agencies are permitted to obtain services from these non-Federal Government SMR systems. The authority for Federal Government agencies to use SMRs was granted by the FCC in 1988.[9]

In granting permission for Federal use of SMRs, the FCC noted that under the concept of SMR service when the FCC established it, SMR licensees may exclude a particular class of users (e.g., Federal Government users) if they do not choose to provide service to that group. The FCC further stated that "Offering additional communication options to the Federal Government is particularly in the public interest because it can reduce the cost of Federal communication services, thereby reducing the burden to the taxpayer." Federal agencies are authorized to use non-government SMRs under the following conditions:

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[9] FCC *Report No. 41-20 In the Matter of Part 90, Subparts M and S of the Commission's Rules,* PR Docket No. 86-404, Specialized Mobile Radio Service, Expansion of Pool of Eligible End Users, Private Carrier Status, May, 1988.

> Federal agencies shall not establish an SMR system or provide an SMR service in the [806-824, 851-869, 896-901, and 935-940 MHz] bands, but shall operate only as an end user with a FCC licensed private carrier on a contractual basis. Since the SMR service is not considered to be in the Common Carrier service, frequency authorization to Federal agencies will be contingent upon the continuation of the negotiated contract with the private carrier. Federal agencies are encouraged to evaluate the efficiency and cost effectiveness between leasing an SMR service, establishing a new land mobile radio system, or expanding their existing system to satisfy their operational requirements.[10]

Currently, the majority of Federal use of leased SMR services on non-government frequencies in the 800 MHz band is in areas where the government has small fleets of vehicles. In these instances the leasing of services is more cost effective than building and maintaining a communications system. Federal agencies, with the exception of the Postal Service and the Department of the Interior, obtain SMR services primarily from local and State government trunking systems. TABLE 3 lists by agency the number of approved leasings of services on non-Federal SMR systems.

Transportable

The requirements section of this report identifies many applications that require the immediate transportation of Federal land mobile systems to different locations. Applications include law enforcement and emergency/disaster relief. All of the land mobile architectures explained above have corresponding transportable systems for use in rapid deployment situations. This is an important requirement for Federal users and is not as prevalent for other land mobile users.

Cellular Telephone

Commercial mobile telephone networks (cellular telephone) provide access to the public switched telephone network. Cellular telephone service has been growing very rapidly. At the beginning of 1992, there were 8 million users, and another 3 million were added during the

[10] NTIA Manual, Supra note 7, Section 8.2.49.

year.[11] Cellular telephone companies provide services to a wide variety of business, government, and private customers. A basic cellular system is illustrated in Figure 4.

TABLE 3
SMR USE BY AGENCY[a]

Federal Agency	SMR Systems
Agriculture	2
Air Force	2
Coast Guard	1
Commerce	1
Energy	1
Environmental Protection Agency	1
Interior	3
Justice	15
Navy	1
Postal Service	26
TOTAL	53

[a]as of July 1, 1993.

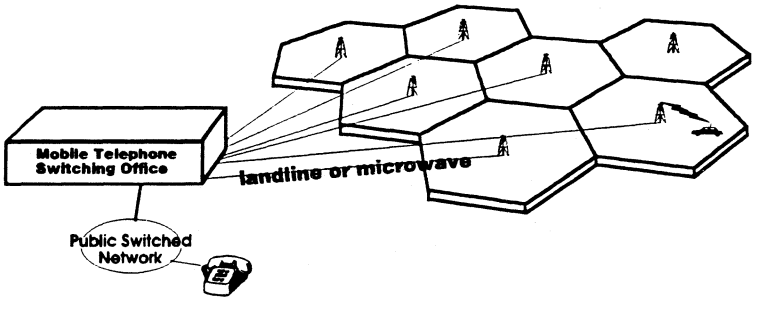

Figure 4. Cellular telephone system.

[11] *Telecommunications Report*, March 8, 1993, page 24.

The Federal Government Interagency Cellular Working Group has reported to NTIA that there are approximately 5000 Federal cellular users within 50 metropolitan areas (exclusive of the Department of Defense).[12] These cellular phones are used primarily when personnel are away from their normal office. Federal use of cellular phones augment existing Government communications and do not replace Government land mobile systems. It is expected that Federal use of cellular telephones and other emerging wireless services will grow quickly over the next several years.

Although Federal Government agencies do use cellular phones, the Federal users do have concerns with Federal use of cellular services. These include the concern that since the Federal Government does not own the infrastructure, nor do these systems operate on government frequencies, there is a possibility of overload and lockout and an inability to gain priority access to the system. Additional problems include security, and the threat of transmission monitoring. The move to digital signaling and encryption will aid in solving the security/monitoring problem. Code Division Multiple Access (CDMA) (spread spectrum, see Section 4) shows promise for avoiding monitoring of signals. The priority access problem is also important and technical means to provide priority access have been developed. An added concern with cellular is the cost of the service. Agencies must consider whether other alternatives such as SMRs can provide functionally equivalent service.

Emerging Wireless Technologies

A future application of the mobile service is expected to develop in the form of emerging wireless services, often referred to as Personal Communication Services (PCS). It is predicted that there may be as many as 40 million PCS users by the end of the century.[13] A variety of mobile telecommunication applications have been suggested for PCS, and in time, a more complete definition of the service will evolve. The FCC has broadly defined PCS as "radio services that encompass a wide array of mobile and ancillary fixed communication services that could provide services to individuals and businesses and be integrated with a

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[12] Interagency Cellular Working Group, Letter Report to D. Cohen (NTIA), March 3, 1993, from R. Otis and C. E. Cape (co-chairmen of working group).

[13] Phillips, A., *PCS Trials and Customer Surveys*, Government Symposium on Land Mobile Radio (LMR) and Personal Communications Systems (PCS), Mclean, VA, December 1-3, 1992.

variety of competing networks."[14] PCS applications are expected to include pocket telephones, paging, wireless Local Area Networks (LAN), wireless Private Branch Exchanges (PBX), wireless communications with multiple functions, image transfer such as fax, and other data services. Already, several companies have developed booksize PCS devices that reportedly combine a cellular phone, note pad, fax machine and personal computer. Generic names for such devices include Personal Digital Assistant and Information Appliance.[15]

At the present time, the telecommunications network contacts a station, but in the future, the network may be intelligent enough to contact an individual regardless of location. PCS will be a key element of the telecommunications infrastructure that will help to accomplish this intelligent network.

Federal Government use of PCS services will supplement rather than supplant the Federal mobile service infrastructure. The Federal Wireless Users Forum is reviewing Federal requirements for PCS and has suggested that Federal PCS requirements may be accommodated by one or more of the following spectrum approaches:

- The use of commercial service by lease or subscription
- The use of PCS frequencies as a secondary government allocation to a primary non-government mobile application
- The use of leased commercial systems on government frequencies
- The use of government owned systems on government frequencies
- The use of dynamic spectrum sharing (An example of this would be the dedicated use of some bands for commercial use with the option for government access in emergencies)
- Operations in non-licensed bands (e.g. wireless LANs and wireless PBXs)

The Department of Energy has formulated a strategic planning program for its Information Resource Management into the 21st Century called IRM Vision 21. Since radio communication services are a critical element of the program, DOE used IRM Vision 21 as a basis for its response to NTIA's NOI on Strategic Spectrum Planning. In the response, DOE predicts that PCS will have a major impact on U.S. and world telecommunications

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[14] FCC First Report and Order on Narrowband Personal Communication Services, General Docket No. 90-314 and ET Docket No. 92-100, released July 23, 1993.

[15] Brodsky, Ira, *Coming! Information Appliances*, Wireless for the Corporate User, Nov/Dec 1992, pp. 9, 10, 50-52.

infrastructure. If DOE projections for the rapid development and deployment of PCS are accurate, PCS will soon be an important element of the mobile radio infrastructure. In particular, DOE offers these predictions for the future of PCS:

> Emerging telecommunications technologies such as Personal Communication Services (PCS) promise effectiveness and efficiency throughout the Federal Government and the United States. PCS will also significantly change the telecommunications infrastructure within the Federal Government... DOE radio communication strategies [include the use of] terrestrial and satellite PCS network systems, when and where feasible and practical, to augment and/or replace existing land mobile communication systems... Terrestrial and satellite PCS networks and systems will be available in the mid to late 1990's. The Federal Government should consider the feasibility of obtaining a PCS version of the Federal Telecommunications System 2000 network... The Department [of Energy] intends to evaluate PCS when available and envisions the potential use of wireless and PCS in the next 5 to 10 years, which will significantly change the telecommunications infrastructure throughout DOE.[16]

Digital Mobile Data Services

Packet radio is a multiple access technology which is useful for bursty data transfer. Data transfer can be utilized to provide information (paging and short messages) and dispatch communications. Packet technology is particularly spectrum efficient because the communication channel is used only when bursts of data are sent and thus the channel can be shared by the multiple users. A variety of commercial packet data networks are already established and include the ARDIS system (Motorola and IBM), and the RAM Mobile Data Network (Ericsson Mobitex). Additionally, the cellular community is examining development of a Cellular Digital Packet Data system that will transmit packet data over idle 30 kHz cellular channels (i.e., short, idle gaps that exist, for example, between spoken words). In this system, data hops to another idle channel when voice takes over the channel.

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[16] Comments of the United States Department of Energy on NTIA's NOI on Current and Future Requirements for the Use of Radio Frequencies in the United States, Docket No. 920532-2132, November 4, 1992.

Aeronautical Mobile

The aeronautical mobile service supports communications between ground stations and aircraft with a significant portion devoted to air traffic control (ATC) and other aeronautical safety communications systems. The frequency bands and standards used for these services are subject to international treaty and are standardized through the International Civil Aviation Organization (ICAO) to ensure worldwide interoperability. Many of these aviation services are used by both Government and non-Government entities.

In high air traffic areas of the world, radio networks have been established in the VHF band to provide continuous overlapping coverage of high capability and high traffic services required for efficient ATC operation. The FAA maintains an extensive network of such radio stations in the United States. The present ICAO standard signal format is voice communications using double-sideband amplitude modulation (DSB-AM) with 25 kHz channeling. The frequency 121.5 MHz is allocated worldwide for VHF safety and distress communications.

The ICAO has been undertaking the study and development of system improvements within the Aeronautical Mobile Communications Panel to increase communications capacity. One such improvement would establish worldwide standardization of a bit-oriented, Aeronautical-Telecommunications-Network-compatible data link. Recommendations for such improvements are expected to be made in early 1995 at a special ICAO divisional meeting. Alternative future system improvements being analyzed include a further channel split of the present 25 kHz channel spacing, or to provide up to four baseband circuits on a single 25 kHz channel in an integrated arrangement allowing both voice and data to be provided on the same 25 kHz channel.

The 225-399.9 MHz band, except for the 328.6-335.4 MHz sub-band (navigational aids) is designated for Department of Defense (DoD) communications requirements. However, nearly 300 channels in this band are allocated for use by the FAA to provide ATC services to the DoD within the United States. These services include enroute communications: ground, local, approach, and departure control at air bases; and weather information data link services. In addition, the frequency 243 MHz is allocated worldwide for UHF safety and distress communications. ATC communications are provided using AM voice (double sideband) on mostly 25 kHz channels in order to assure compatibility with all DoD aircraft.

New systems in the Aeronautical Mobile Service allow passengers in commercial aircraft to place telephone calls while in flight. These systems are full-duplex systems operating in the 849-851 and 894-896 MHz bands, currently using pairs of narrowband AM channels with 6 kHz channel spacing. Shortly, these AM channels will be replaced with full digital channels that will allow customers to receive voice and data. Use of such systems is expected to grow as the public continues to want more access to convenient personal communications.

Aeronautical mobile-satellite systems are regarded to be outside the purview of this report, but they are included here because of their anticipated impact on future air-ground communications. Satellite communications greatest potential is its ability to improve air-traffic service operations in areas of the world where terrestrial communications are not practical. The implementation of these systems in the 1990's will take advantage of the worldwide infrastructure of the INMARSAT system and the growing number of domestic and regional systems.

Aeronautical mobile systems have the potential to cover much larger areas from a single ground station location than other land mobile systems. A VHF voice channel in the 117.975-137 MHz band can cover distances exceeding 200 nautical miles from a single point. The spectrum efficiency of air traffic systems varies depending on service area size, altitude, and system type. Because of the international nature of civil aviation, implementation of new system capabilities must be on a gradual, cost-efficient basis taking into account both the system user and provider communities.

Maritime Mobile

Federal maritime mobile service communications support the operation, movement and safety of shipping on navigable waters of the United States and on the surrounding seas. The Coast Guard has major responsibilities for maritime safety and navigation, but many radio requirements are set by international treaty under the auspices of the International Telecommunication Union (ITU) and the International Maritime Organization (IMO). The ITU/IMO regulations are the basis for many domestic maritime regulations issued by the FCC and NTIA.

The only exclusive government allocation for the maritime mobile service in the bands between 30-3000 MHz is at 157.0375-157.1875 MHz. This 150 kHz band is divided into six

25 kHz channels. Five are used to support the National VHF-FM Distress and Safety System operated by the Coast Guard. The remaining channel is used by Federal agencies as a working frequency for their maritime operations.

Other national maritime mobile service allocations in the bands between 156.2475 and 162.0125 MHz are administered by the FCC. Maritime mobile usage is governed by international treaty (ITU Radio Regulations) and specified FCC regulations. Federal use of these allocations must be in compliance with international and domestic regulations to ensure interoperability with all shipping and to maintain the integrity of maritime distress and safety communications.

Maritime mobile service use in the government fixed and mobile bands between 30-3000 MHz is primarily to support government agency requirements to interface with civil land and aeronautical mobile service operations.

Defense Tactical Systems

Military tactical use of the radio frequency spectrum is required to support wartime, peacetime, and training operations of the total force. The highest priority military tactical uses include command and control, weapon and fire control, intelligence and electronic warfare. The employment of military tactical forces by nature includes movement by ground, air, and sea platforms, and which are engineered to meet unique specifications for combat. Military tactical use of the spectrum differs from civil use in requisite flexibility, availability and security. Tactical equipment also differs from base or permanent station telecommunications in that it is deployed with the tactical force. Nationally, tactical operations are usually compatible with other users in the same band. Internationally, users must recognize ITU, host nations and military alliance allocations in military operations around the world.

Many military missions are carried out under dynamic conditions and involve system interconnections. The nature of military operations is such that requirements, usage, and even the frequency varies depending on the nature of the operation. Specifically, during tactical battlefield conditions (conditions that are not predictable or controllable) operational flexibility is the key requirement for successfully completing any mission. Furthermore, a single piece of equipment listed in any one band is only one part of the total system. Changes in any single part of the system can force changes in other parts of the integrated military system.

Equipment used to meet this operational flexibility, especially in tactical situations, must be able to survive under extreme, adverse conditions (e.g., environmental extremes, jamming, explosive and radiation hazards) to operate anywhere in the world. Commercial telecommunications systems generally are not required to be this survivable, and their use could result in the loss of command and control capability to direct the nation's military forces during tactical situations. Thus, in the interest of national security, the military obtains the necessary equipment via a source selection process that ensures a quality, cost-efficient product that has met the stringent DoD military standards (MIL-STD) requirement. These DoD MIL-STD requirements are more stringent than regulatory standards for commercial equipment.

SECTION 4
SPECTRUM EFFICIENT TECHNOLOGIES AND COST-EFFECTIVE MEASURES

The Organization Act requires the use of spectrum efficient technologies that are at least as spectrum efficient and cost-effective as readily available commercial radio systems. This section reviews those factors which lead to spectrum efficient operation or cost effectiveness.

SPECTRUM EFFICIENT TECHNOLOGIES

This subsection reviews the technologies useful for mobile communications. Hatfield, et al., defined three general technological methods to increase spectrum efficiency for land mobile systems as follows:[17]

(1) Channel splitting techniques (rechannelization) and changes in modulation
(2) Added traffic load
(3) Spatial reuse of frequencies

Table 4 lists current and developing technologies for mobile applications organized into the above generic methods. Our interests in these technologies are a comparison of their individual advantages relative to spectrum efficiency.

There are various mathematical definitions of spectrum efficiency. For land mobile systems the definition most often used to compare different technologies equates the spectrum efficiency to the maximum number of simultaneous (time domain) users which can utilize a land mobile system in a specific geographical area (spatial domain) and a specific portion of the radio spectrum (frequency domain). This definition will be adopted here. The following is a review of spectrum efficient technologies.

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[17] Hatfield, D.N., G.C. Ax, and A.C. Miller, *The Role of New Technologies and Spectrum Management in Meeting the Demand for Private Land Mobile Radio Telecommunications Capacity*, November, 1982, p. 36.

TABLE 4
SPECTRUM EFFICIENT METHODS AND SUPPORTING TECHNOLOGIES

Spectrum Efficient Methods	Supporting Technologies
Channel Splitting (Narrowbanding) and Modulation	Narrowband analog FM Digital modulations SSB/Companding modulations
Increased Traffic Load	Trunking Multiple Access (FDMA,TDMA, CDMA) Digital Compression
Spatial Reuse	Power considerations Antenna considerations Cellular systems Frequency Assignment Methods

Channel Splitting Techniques and Changes in Modulation

Channel splitting. NTIA and FCC have developed channeling plans for bands allocated to mobile services. Channeling plans divide the allocated band into frequency channels. Over time, the mobile bands have been continually rechannelized on narrower and narrower channels thus allowing more users into a portion of spectrum.

Changes in modulation. During the fifties and sixties channel bandwidths for analog FM ranged from 40 to 100 kHz. These bandwidths have been reduced to current values ranging from 20 to 30 kHz. In Europe and Japan systems are already using a 12.5 kHz channel bandwidth for analog FM. There is a lower limit for analog FM bandwidth as far as system performance is concerned. In particular, when the modulation index for analog FM is below 0.6, FM looses its superiority to AM modulation.[18] Thus, there is a limit to how narrow the bandwidth can be for analog speech with FM modulation and a 12.5 kHz bandwidth is close to the limit.

Spectrally efficient alternatives to analog FM are becoming increasingly available and are constantly being improved through advances in technology such as digital encoding,

[18] Singer, E., *Land Mobile Systems*, Section 7.4, Prentice-Hall 1989.

compression methods and new analog and digital modulation methods. A description of some of these new technologies follows.

New spectrally efficient modulation methods for digital voice signals are becoming increasingly available. These include pre-modulation filtering and constant envelope and linear modulation methods. The bandwidth efficiencies (measured in bits/second/hertz) for several of these modulations are summarized in TABLE 5. Although not shown as a specific efficiency in the table, spread spectrum direct sequence pseudo random Phase Shift Key (PSK) modulation when combined with Code Division Multiple Access (CDMA) is predicted to be quite spectrum efficient.[19]

TABLE 5
SPECTRUM EFFICIENCIES FOR DIGITAL VOICE CODING MODULATION METHODS[20,21]

Type of Modulation	Source/User	Capacity		Efficiency (b/s/Hz)
		Rate (kb/s)	Bandwidth (kHz)	
$\pi/4$ QPSK	IS-54	48.6	30	1.62
QPSK-CDMA	IS-95	1228	1250	N users
GMSK	GSM (Europe)	270.833	200	1.35
4-ary FM/QPSK-C	APCO 25	9.6	12.5	0.77
QPSK-C	future	8	6.25	1.28
16 QAM	future	?	?	3.5

[19] Lee, William C. Y., *Overview of Cellular CDMA*, IEEE Transactions on Vehicular Technology, Vol. 40, No. 2, May 1991.

[20] Fehr, Kamilo, *Modems for Emerging Digital Cellular - Mobile Radio Systems*, IEEE Transactions on Vehicular Technology, Vol. 40, No. 2, May 1991, pp. 355-365.

[21] Davidson, A. and L. Marturano, *Impact of Digital Techniques on Future Land Mobile Spectrum Requirements*, IEEE Vehicular Technology Society News, May 1993.

Quadrature Phase Shift Keying (QPSK) and Gaussian Minimum Shift Keying (GMSK) are examples of methods for digital encoded information and Time Division Multiple Access (TDMA). Modulation techniques suggested for channel splitting to create narrowband channels are 4-ary FSK and QPSK-C.

The data in TABLE 5 points out one difficulty with narrowbanding channels to 12.5 kHz or 6.25 kHz for data transmission purposes. The bit rates for these bandwidths are 9.6 kb/s and 8 kb/s, respectively. Although these bit rates may be sufficient for voice communication, they may not be adequate for future data applications which may require sending images and large data files in a reasonable amount of time for mobile applications (e.g., 5-10 seconds). Channeling plans can be designed to allow the flexibility to stack narrowband channels together to support larger capacity data applications while yielding equivalent spectrum efficiency.

One analog technique which uses a bandwidth narrower than 12.5 kHz for voice and data is Single Side Band (SSB) in various forms. These SSB modulation methods are for use in narowband channels of 5 or 6.25 kHz bandwidths. One method is Amplitude Compandored Single Sideband (ACSSB). ACSSB systems use a single-sideband AM signal transmission technique with a pilot tone. The pilot tone is used for establishing a reference amplitude for decompression, as well as an accurate reference frequency for the single-sideband detector. Compression of the amplitude-modulated signal (amplitude compression) before it is transmitted produces more uniform transmitter output power, while decompression (expansion) of the signal in the receiver provides better dynamic range and lower background noise. The 220-222 MHz band can be viewed as a test-bed for these techniques.

Increased Traffic Loading

Trunking. A primary advantage of trunking is its ability to significantly increase total traffic loading on individual channels and still provide a high probability of immediate access to users (i.e., a channel is available when needed). This is accomplished by spreading the statistical, randomly-occurring user requirements over a number of channels.

The technical data included in the Appendix illustrates that trunking offers its greatest spectrum efficiency advantage when a trunking system is sufficiently loaded. Moreover, the improvement in spectrum efficiency from using trunking is greatest when users can tolerate only a small probability of being blocked. As an example of the spectrum efficiency advantage

of trunking, the Appendix demonstrates that a five channel system, appropriately loaded, is about 3.5 times as efficient as a non-trunked system for an 85% probability of not being blocked. It is for this reason that the FCC has specified loading criteria. The loading standards established by the FCC for trunking systems operating above 800 MHz require licensees to load their systems to 70 mobiles per channel to retain their licenses and to obtain additional channels.[22] Some alternative rules apply to rural areas.

There are several "upgraded" trunking architectures that offer greater spectrum efficiency. While increasing spectrum efficiency, the use of these "upgraded" trunking architectures adds increased complexity and corresponding increased development and implementation costs. One of these "upgrades" is simulcasting. A simulcast trunking system covers a larger geographical area by simultaneously transmitting the same signal using the same frequencies for the total coverage area. A second "upgrade" is Enhanced Specialized Mobile radio (ESMR) first implemented by Nextel Communications Inc. (formerly Fleet Call) in Los Angeles, 1993. Nextel, in response to the NTIA NOI for long-term planning of the spectrum, quantified the spectrum advantages of this trunking method:

> These systems incorporate innovative state-of-the art technology including digital speech coding and Time Division Multiple Access (TDMA) transmission to create six voice channels using a single 25 kHz frequency. They represent the first application in a dispatch-capable communication system of a multiple, low-power base station configuration permitting geographic reuse of frequencies. Together, these innovations yield in excess of 15 times the customer capacity of existing SMR systems.[23]

In summary, the advantage for trunking from a spectrum efficiency perspective is an increased volume of traffic in the same amount of spectrum utilized by conventional non-trunked systems. Additionally, as pointed out by Hatfield, et al., (1982), trunked systems can mix disparate users (i.e., frequent users with sporadic users).

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[22] Code of Federal Regulations, Title 47, Part 90, Section 631, 47 CFR 90.631, October 1, 1991.

[23] Comments of Fleet Call on NTIA's NOI on Current and Future Requirements for the Use of Radio Frequencies in the United States, Docket No. 920532-2132, November 1992.

Multiple access methods. There are three types of multiple access technologies which provide dedicated access: Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA). With FDMA the total frequency band is divided into narrower channels and each of these channels is utilized by only one user during its time of communication. In TDMA several users have access to a given channel and simultaneous communication is achieved by having the users transmit in different coordinated time slots. In CDMA the total allocated bandwidth is utilized simultaneously by all transmitters using uniquely coded signals to provide non-interfering access to the spectrum. The signalling utilized for CDMA is spread spectrum.

Considerable testing, research, and development is underway to determine the advantages and disadvantages of each of these multiple access methods. TDMA and CDMA provide alternate methods in lieu of FDMA narrowbanding to efficiently utilize the spectrum for mobile services. Many spectrum efficiency comparisons of FDMA, CDMA, and TDMA have been made. Already, TDMA has been selected for use in ESMR trunking systems to be deployed this year (1993) in spectrum congested locations such as Los Angeles.[24] CDMA is a serious contender for new mobile uses (e.g., PCS and digital cellular) and may have the potential to overlay users on existing fixed and mobile allocated bands.[25]

Digital voice compression. The most dynamic move in telecommunications has been to digital coding for voice and video. Digital coding has some inherent advantages over previous analog methods. These include the ability to mix voice and data, and with the addition of error correction, digital systems have greater coverage range than analog systems. Note, however, that the performance for digital systems drops off quickly beyond a certain range.

A voice signal can be digitally coded and reconstructed with very good quality if it is sampled at 8000 samples/second with 8-bits/sample using 256 quantization levels yielding 64,000 bits/second. This is a significant bit rate to transmit, especially for a mobile voice channel. There is, however, an inherent redundancy in speech signals. Compression techniques eliminate redundancy and are able to reduce the bit rate required to send voice significantly below the 64,000 bits/second rate. For example, based on the definition of

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[24] Ibid.

[25] Schilling, D. L., G. R. Lomp, J. Garodnick, *Broadband CDMA Overlay*, IEEE Vehicular Technology Symposium, 1993.

spectrum efficiency, if the required bit rate to transmit speech can be reduced to 4800 bits/second the efficiency will be multiplied by 12.5 (i.e., 64000/4800). The required bit rates for various speech coders suggested for mobile use range from 32 kb/s which uses an Adaptive Delta PCM (ADPCM) source coder to a 2.4 kb/s linear predictive (LPC) waveform Coder. Speech compression is an area of active research and great accomplishments in compression methods can be expected in the next decade.

Another method to improve spectrum efficiency is Forward Error Correction (FEC) which is utilized to correct bit errors that occur during the transmission. Along with compression and FEC, great strides are also being made in encryption methods and it is expected that new encryption methods will advantageously be utilized for mobile communications.

Spatial Frequency Reuse

When a frequency is used in a particular geographic region its use is denied in the surrounding regions because of possible co-channel or adjacent channel interference. This spatial frequency reuse concept is used in existing cellular telephone systems, and is a major contributor to the high spectrum efficiency of those systems. The frequency reuse distance depends on a variety of technical parameters including transmitter power, antenna gain, required reliability, modulation method, and the method of channel coding (if used). Some PCS systems will use microcell structures, while in-building systems, such as wireless PBXs and LANs, may use even smaller picocells. At least two benefits are gained by using smaller cell sizes: the power required for transmission from a mobile unit is decreased, and the number of cells in a given area can be increased. A greater number of cells leads to increased spatial frequency reuse thus increasing spectrum efficiency.

Frequency assignment methods. Along with re-channelization, the algorithms for how the re-channelized frequencies are assigned are also important. Assignment efficiency includes those factors in the assignment process that allow the maximum amount of use to be derived from a channel or group of channels. One possible example of assignment efficiency for land mobile operations is the practice of reserving a certain set of frequencies for base station transmitters only, and another set (usually paired with channels of the first set) for mobile transmitters.

COST EFFECTIVENESS

Future Federal land mobile systems, in addition to being spectrum efficient, will also need to be cost effective. Measures which promote cost effectiveness include the following: (1) use of off-the-shelf equipment, (2) use of economies of scale, (3) use of economies of scope, (4) use of a sufficient number of users to make cost-per-user reasonable, and (5) synchronization of equipment replacement with exhaustion of equipment lifecycle.

Off-The-Shelf Equipment

The most economical radios are purchased as off-the-shelf items since the considerable effort to develop and produce new spectrum efficient mobile radios is a private sector effort. These new radios to be used by local and State law enforcement and commercial users should eventually be available as off-the-shelf radios. The technical requirements for Federal land mobile radios are similar to the technical requirements for the State and local law enforcement radios. Accordingly, the Federal sector, to be both cost effective and spectrum efficient, should be able to satisfy many of its land mobile communication needs by simply purchasing commercially available off- the-shelf radios.

It is acknowledged, however, that radios with unique characteristics, different from those produced for the private sector will be needed for certain land mobile requirements such as in certain military applications.

Economies of Scale

Economies of scale result when a large number of units with similar technical characteristics are produced, thus reducing the individual cost of each unit. The greatest economy of scale would occur if all equipments used in the various government and non-government land mobile bands had similar technical characteristics. Similar technical characteristics may include modulation method, channel bandwidth, or voice coding schemes. One step towards economy of scale could be realized, for example, if Federal users and State and local law enforcement agencies used the same type radio.

Economies of Scope

Another economy for telecommunication systems is economy of scope. Reed (1993) defines "economy of scope" to exist between telecommunication systems when "the cost of providing these services over one network is less than the combined cost of separate networks."[26] As an example, a campus area, city-wide or area-wide system (e.g., trunking) which can provide communication for a number of Federal entities can be cost effective or achieve "economy of scope" if the cost for the area-wide system is less than the total cost for individual entity systems. The joint use among entities may be a "...means to improve interoperability, and permit efficient use of limited resources (spectrum, personnel, funding)."[27]

Sufficient Number of Users

Several of the spectrum efficient mobile radio architectures require additional equipment such as antennas, transmitters, telecommunications interconnections among sites, and complex computer processing to achieve the spectrum advantage. These include: trunking, spatial zoning, and cellular frequency reuse systems. The utilization of these technologies adds considerable initial implementation costs. Systems that use these technologies must have a sufficient number of users to make them economically viable and cost effective (cost spreading).[28]

Equipment Life Cycles

New radio communication technology which is more spectrum efficient than previous technology will continually enter the market place in the next decade. To be cost effective, however, land mobile users cannot continually replace their existing technology when new technology becomes available. New equipments should be phased-in (migrated) in such a manner that equipment replacements with improved spectrum efficiency characteristics occur

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[26] Reed, D., *The Cost Structure of Personal Communication Services*, IEEE Communications Magazine, April 1993, pp. 102-108.

[27] Proceedings of the Federal Wireless Users Forum Workshop, May 1993.

[28] Hatfield, Supra note 17.

during system changeover. This minimizes costs for the Federal Government sector. The lifetime for land mobile equipment is generally accepted to be about ten years.[29]

[29] Reed, Supra note 26.

SECTION 5
MOBILE EFFICIENCY PLAN OF ACTION: Federal Technical and Operational Standards

One of the objectives of the NTIAOA is to assure that the radio technologies (i.e., the radio equipments) used by government land mobile users are at least as spectrally efficient as that used by the commercial sector. NTIA and the FCC assure the spectrum efficiency of radio equipments by establishing technical and operational regulatory standards. This section is a comprehensive description of the plan of action for radio technology standards.

TECHNICAL STANDARDS: RECHANNELIZATION OF FEDERAL LAND MOBILE BANDS

TABLES 6 and 7 provide an overall summary of the current (January 1993) applicable FCC and NTIA technical standards and usage in the private and Federal sectors, respectively. An explanation of the technical characteristics shown in these tables and how they relate to spectrum efficiency is provided in Section 4. A discussion of the radio requirements and techniques is included in Section 3.

A comparison of TABLES 6 and 7 illustrates that the majority of the radios used in both the Federal Government and commercial non-government sectors are the same analog FM radios with 16 kHz necessary bandwidths. Thus, currently (January 1993) the spectrum efficiency of the radio technology is the same in the Federal Government and commercial sectors.

Radio technology is changing rapidly, and as time progresses the radios being manufactured will likely have increasingly improved spectrum efficiencies. These radio technology changes include, among other things, the move to digital signalling, audio compression, and spectrally efficient modulations. These new radios and the supporting technologies are described in Section 4 of this report. The introduction of these new spectrally efficient technologies will allow more users to use a given portion of the spectrum thus achieving greater spectrum efficiency.

Federal land mobile usage is growing rapidly in support of increased Federal service to the public. The 162-174 MHz band has more frequency assignments than any other Federal mobile band used for land mobile applications. The number of frequency assignments in the 162-174 MHz band grew at a rate of 6% between 1990 and 1992. A migration to narrowband equipment commenced in 1989 when NTIA and the Federal agencies began an

effort to develop a narrowband standard for Federal users in the 162-174 MHz land mobile band. Note that the inception of the NTIA effort to rechannel the Federal Government land mobile bands predates the Telecommunications Authorization Act of 1992.

TABLE 6
SUMMARY OF LAND MOBILE STANDARDS AND USAGE FOR THE PRIVATE LAND MOBILE RADIO SERVICES (JAN 1993)

Band (MHz)	Equipment Necessary Bandwidth	Channel Spacing (kHz)	Typical Purpose
25-50[a]	16 kHz analog FM	20	Conventional
150-174[a]	16 kHz analog FM	15[b]	Conventional and paging
450-470[a]	16 kHz analog FM	25	Conventional and paging
470-512[c]	16 kHz analog FM	25	Conventional
806-824, 851-869	16 kHz analog FM	25	Conventional and trunked
896-901, 935-940	11 kHz analog FM	12.5	Conventional and trunked
929-930	-	25	Paging

[a] Portions of this band are for Federal Government and/or common carrier use only.
[b] Some 30 kHz channels are available for the Business Radio Service. Adjacent channels are not assigned to avoid necessary bandwidth overlap.
[c] Band is available in 13 urbanized areas on a shared basis with UHF TV.

TABLE 7
SUMMARY OF LAND MOBILE STANDARDS AND USAGE FOR FEDERAL AGENCIES (JAN 1993)

Band (MHz)	Equipment Necessary Bandwidth	Channel Spacing (kHz)	Typical Purpose
30-50[a]	16 kHz analog FM	20	Conventional
138-150.8[a]	16 kHz analog FM	25	Conventional
162.0125-174[a]	16 kHz analog & digital FM	25	Conventional and paging
406.1-420	16 kHz analog & digital FM	25	Conventional and Trunking

[a] Portions of this band are for non-Government use only.

NTIA and the Federal agencies examined a number of alternatives for migration before settling on a migration to 12.5 kHz radios. Influencing their decision were the ongoing developments in digital signaling technology and the fact that 12.5 kHz analog technology was already being used successfully abroad and in the private sector (see TABLE 6). In addition, it was clear that Federal, State, and local law enforcement agencies were likely to adopt a 12.5 kHz digital standard to ensure interoperability.[30]

Rechannelizaton of the mobile bands that are used for land mobile applications, or the use of TDMA in the existing bandwidth (see Section 4), compels the use of new spectrum efficient technologies and thereby facilitates accommodation of more users in the existing Federal Government mobile spectrum. Accordingly, NTIA will assure that the Federal Government bands that are used for land mobile applications are rechanneled to narrower bandwidths as appropriate. The following subsections contain a specific band-by-band rechanneling plan and schedule of implementation for the Federal Government land mobile bands.

406.1-420 MHz Band

Between 1990 and 1992 the number of Federal Government assignments in the 406.1-420 MHz band grew at the rate of 12% per year.[31] Currently, there is a dramatic growth in the 406.1-420 MHz band for Federal use of land mobile trunking.

The 25 kHz channeling plan for the 406.1-420 MHz band currently provides for 556 channels and includes provisions for conventional and trunked mobile operations, and wideband fixed operations. The Federal Government is presently the sole user of land mobile trunking systems within the United States that use frequencies below 800 MHz.

Plan and Schedule. Prior to passage of the Telecommunication Authorization Act of 1992, NTIA and the Federal agencies began development of a migration plan to rechannelize the 406.1-420 MHz band from 25 kHz (16 kHz necessary bandwidth) to 12.5 kHz (11 kHz

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[30] Associated Public-Safety Communications Officers Inc. (APCO) Project 25, *Proposed Over-The-Air Standards*, January 1993.

[31] Speights, William D., et al, *National Land Mobile Spectrum Requirements*, NTIA-TM 93-XX, (to be published).

necessary bandwidth) channels. The 12.5 kHz plan will commence for new equipments in 1995 and the changeover for existing equipments is in 2008. NTIA and the Federal agencies should complete the development of the channeling plan by January 1, 1994. The channel allotments in the plan will allow the Federal Government agencies the flexibility to "stack" adjacent 12.5 kHz channels for use with wider bandwidth (e.g., 25 kHz) TDMA access techniques to achieve an equivalent or higher level of spectrum efficiency. It is expected that the new channeling plan will effectively double the number of available channels.

220-222 MHz Band

Plan and Schedule. In 1988, the 220-222 MHz band was reallocated to the land mobile service and its use was restricted to 5 kHz (4 kHz necessary bandwidth) narrowband technologies. ACSSB and digital linear modulations are examples of the types of narrowband technologies that may be used. The channeling plan includes 200 channel pairs; ten of which are exclusively for Federal Government use (nationwide), and 140 of which are shared equally with non-Government users.

162-174 MHz Band

Plan and Schedule. In the fall of 1992, NTIA adopted a 12.5 kHz (11 kHz necessary bandwidth) channeling plan for the 162-174 MHz band. The 12.5 kHz plan commences for new equipments in 1995 and requires changeover for existing equipments in 2005. Other technical standards (e.g., spectrum masks for unwanted emissions, adjacent channel selectivity) to accompany this rechannelization have been defined and are included in Section 5.6.2 of the NTIA Manual.

The 162-174 MHz channeling plan effectively doubles the number of available channels from the previous total. The specific channeling plan is in Section 4.3.7 of the NTIA Manual. Since the Federal Government uses few interstitial frequencies, it is expected that rechanneling will approximately double the number of Federal users that can operate in a geographic area after the migration to 12.5 kHz channel spacing is complete (a ten-year process).

The adoption of a 12.5 kHz channeling plan does not require the use of a specific radio technology (e.g., modulation or coding method) but permits a smooth transition from 25 kHz

radios (with necessary bandwidths of 16 kHz) to 12.5 kHz radios (with necessary bandwidths of 11 kHz) that use either analog or digital technology. The channel allotments in the plan allow the Federal Government agencies the flexibility to "stack" adjacent 12.5 kHz channels for use with technologies that produce equivalent or superior spectrum efficiency.

138-150.8 MHz Band

The National Table of Frequency Allocations for the 138.0-150.8 MHz portion of the spectrum is divided into six different segments. The bands 138-144, 148.0-149.9 and 150.05-150.80 MHz are allocated to the Federal Government fixed and mobile services and are used principally by the military services. The military services use these bands for both conventional and tactical operations that require worldwide interoperability. Other portions of the 144-148 and 149.90-150.05 MHz bands are allocated to the non-government mobile and other services. The 1992 World Administrative Radio Conference allocated the bands 148-149.9 and 149.9-150.05 MHz for mobile satellite applications.

Plan and Schedule. NTIA will adopt a migration plan that rechannelizes the land mobile portions of the 138-150.8 MHz band from 25 kHz (16 kHz necessary bandwidth) to 12.5 kHz (11 kHz necessary bandwidth) channels. The effort to develop a channeling plan will commence immediately after the NTIA and the Federal agencies complete the 406.1-420 MHz channeling plan. As scheduled, the work effort should commence in early 1994. The 12.5 kHz plan commences for new equipments in 1998 and the changeover for existing equipments is in 2008. A channeling plan for this portion of the spectrum will have to take into consideration the various allocation and operational constraints discussed in the previous paragraph.

30-50 MHz Band

The current channeling plan for Federal Government use of the 30-50 MHz band specifies 20 kHz channels with 16 kHz necessary bandwidths. The current growth in the number of assignments for Federal Government use in this band is 3%.[32] Communications in this portion of the spectrum are affected by man-made noise and ionospherically propagated interference from distant sources during periods of high sun spot levels.

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[32] Ibid.

Plan and Schedule. NTIA does not propose to change the channel spacings for this portion of spectrum at this time. Similarly, the FCC currently has no announced plans to rechannel the private land mobile portions of the 30-50 MHz band.

FCC Regulatory Impact on the NTIA Rechannneling Plan/Schedule

In order to promote more efficient use of the private-sector land mobile bands, the FCC issued a proposed rule-making (NPRM) to regulate the private-sector land mobile bands below 512 MHz.[33] One aspect of the rule-making is to develop spectrum efficiency standards. One of the standards includes a migration to 5 or 6.25 kHz channel spacing for these bands. Some of the respondents to the NPRM were unsure whether proven technology is available to make these narrowband channel spacings possible. There was additional concern about the limited transmission capacity (measured in bits/second) associated with such bandwidths. Others, however, supported the FCC NPRM stating that the technology is indeed available and the greatest spectrum efficiency is realized by using 5 or 6.25 kHz channel bandwidths. The FCC held a roundtable discussion in early May, 1993 to critique the various technologies such as 5, 6.25 and 12.5 kHz systems. There was no clear consensus at the roundtable as to which approach is best.

The NTIA government mobile implementation plan and schedule described above is based on a migration to 12.5 kHz technology. The FCC's rechannelization decisions in its "refarming" proceedings will have an impact on which technologies the Federal Government agencies will eventually use (see Background, Section 1 for a description of refarming). Should the FCC decide to implement 5 or 6.25 kHz channel spacing, NTIA will revisit the plan and schedule since commercial and local/State government sector mobile requirements will be the focal point for the development of new land mobile technologies and equipment technical characteristics. To be cost effective (See section 4), the Federal Government sector will buy off-the-shelf equipment with characteristics similar to those used in the private sector. The commonality of equipment between the private and Federal sector will lead to economies of scale.

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[33] FCC, Supra note 3.

Utilization of Code Division Multiple Access (CDMA)

One of the techniques regarded as being spectrally efficient is CDMA. CDMA assigns a different code to each user, facilitating the co-existence of multiple users in the same portion of the spectrum. The Federal Government was the original developer and the first to make application of CDMA. Recently, CDMA has emerged as an alternative for digital cellular telephone and emerging wireless technologies including PCS. To date there has not been significant action to apply CDMA to the most common land mobile architectures such as repeaters and trunking (see Section 4 for a description of the architectures). If CDMA does emerge as a viable alternative for these architectures, the channeling plans defined above may need to be reviewed to possibly convert channels for CDMA access. Overlaying CDMA on top of the existing systems is another alternative that may need to be considered.[34]

OPERATIONAL STANDARDS: EFFICIENT SPATIAL REUSE OF THE MOBILE SPECTRUM

One method of efficiently using the spectrum resource is to assign frequencies in such a manner that they are spatially reused to the maximum extent possible. The technical rationale for the spectrum efficiency advantage of spatial frequency reuse is described in Section 4.

NTIA currently reviews Federal agency frequency assignment requests using a computerized interference cull method to identify requested frequencies which may cause interference to existing operations. The separation distances included in the cull procedure are largely generated using empirical methods. When a possible interference problem is identified by the cull, the agencies work together to satisfy the requested assignment. This may require the decision to use directional antennas, other antenna constraints, or to reduce transmitter power.

Engineering models have been developed to calculate specific distance separations required to achieve compatibility. Use of these models instead of the empirical methods will lead to better and more efficient use of the spectrum.

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[34] Schilling, Supra note 25.

Federal working groups are currently evaluating methods that will provide a uniform, standardized approach to frequency selection that will assist users at all levels of the frequency assignment process. The methods being considered employ sound spectrum engineering criteria and computational methods for Electromagnetic Compatibility (EMC) analysis and service protection, while accounting for the existing Federal spectrum management policy, plans, rules and regulations. Associated issues such as CD-ROM database enhancement to the Government Master File (GMF) data forwarding systems, and Personal Computer (PC) equipment standardization are also being considered.

NTIA believes that an automated computer processing procedure for frequency assignments based on sound engineering principles will maximize spatial reuse of frequencies for both mobile and other services, and thus will accomplish greater spectrum efficiency. Accordingly, NTIA will coordinate the development of a PC-based automated frequency selection, validation and assignment authorization process by which all Federal agencies can use uniform and standard engineering and application software to select frequencies. In particular, this software for use by the agencies will:

(a) select radio frequencies in accordance with channeling and allotment plans to satisfy a proposed use;
(b) validate that the proposed frequency will not cause nor receive unacceptable interference by performing EMC analysis using agreed upon engineering criteria;
(c) assure that the proposed frequency is the best available for use based on current policy and rules concerning spectrum management;
(d) prepare a frequency assignment proposal for submission to NTIA;
(e) validate proposal data entries for compliance with the NTIA Manual;
(f) flag proposals that are not in accordance with the Table of Frequency Allocations and other adopted policy.

Automation improvements as listed above are scheduled for completion by March 1995. When completed, the software will be provided to the Federal agencies as a tool that they may use to:

- select radio frequencies,
- determine the validity of the selection, and
- electronically provide frequency assignment proposals to NTIA.

After the frequency assignment proposals are submitted to NTIA, NTIA will:

- review, evaluate, and process frequency assignment proposals;
- electronically coordinate the proposals through the Frequency Assignment Subcommittee (FAS);
- electronically notify the FAS of each proposal's status on a daily basis; and
- enter the assignment record into the GMF.

SECTION 6
POLICY ISSUES

INTRODUCTION

There are increasing demands in the United States for both existing mobile communication services and totally new ones seeking to enter the marketplace. Existing services include conventional land mobile dispatch services, specialized mobile radio services and common-carrier mobile radio services (pagers and cellular telephones), while new services include the widely anticipated Personal Communication Services, mobile communications services for notebook computers and other wireless devices. NTIA and the FCC, to help ensure that present and future requirements for existing services can be satisfied, have both undertaken efforts aimed at using spectrum allocated for land mobile services as efficiently as possible. Likely outcomes include provisions that increase the total number of available operating channels within existing spectrum allocations and encourage new technologies permitting more users on each channel.

The pressing needs of the United States, in both the Government and non-Government sectors, for more high-technology, land mobile communications services require that the spectrum be used as efficiently as practicable by all. The earlier efforts of NTIA and the FCC, as well as those to be undertaken in response to the NTIAOA,[35] help relieve demands for more spectrum to expand existing types of service. Spectrum demands for the new types of service currently under development cannot be met as easily since there is no suitable, unused spectrum available. To help solve this problem, Congress, after finding that the scarcity of assignable frequencies for licensing by the FCC will impede technology and limit the capacity and efficiency of U.S. telecommunication systems,[36] has enacted and the President signed into law August 3, 1993 an amendment to the NTIAOA that requires a total of 200 MHz of Government controlled spectrum to be reallocated for non-Government use.[37]

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[35] NTIAOA, Supra note 1.

[36] *House Report Filed on Spectrum Competitive Bidding and Spectrum Reallocation Legislation*, (House Report), U.S. Congress, House of Representatives, May 14, 1993, p 33.

[37] Part B—*Transfer of Auctionable Frequencies*, NTIAOA, Sec. 111-117, Supra note 1.

The following subsections discuss the provisions of the NTIAOA requiring NTIA to develop a plan for the use of more spectrum-efficient technologies in Government mobile radio systems and strengthening NTIA authority to regulate Federal mobile radio services to further the goal of efficient and cost-effective use of the spectrum. Next, current NTIA regulations listed in the Manual of Regulations & Procedures For Federal Radio Frequency Management (NTIA Manual) are described.[38] Then, in order to determine appropriate types of regulation for Federal land mobile communication services and to keep NTIA regulations from conflicting, other Government regulations concerning the acquisition of telecommunication resources are examined.[39] Finally, changes to the policies and procedures used by NTIA for managing Federal Government use of land mobile radiocommunication services are proposed. These include provisions that will continue to encourage introduction of more spectrum-efficient technologies and methods.

ANALYSIS OF POLICY

Current NTIA Policies

NTIA policies encourage the use of both commercial services and spectrum-efficient technologies. Section 2.3.3 of the NTIA Manual calls for the use of commercial services whenever possible.[40] Section 2.3.10 encourages efficiency and effectiveness of use, although

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[38] NTIA Manual, Supra note 7.

[39] These include:

Executive Office of the President, Office of Management and Budget, Subject: *Performance of Commercial Activities*, Circular No. A-76 (A-76), Transmittal Memorandum No. 11, March 19, 1992.

Federal Information Resources Management Regulations (FIRMR) 41 C.F.R. 201. And General Services Administration, FIRMR Bulletins C-1 *Sharing Telecommunication Resources*, January 30, 1991, and C-15 *Mandatory local telecommunication service*.

[40] The Federal Government places heavy reliance on the private sector in providing telecommunication service for its own use . . . [A]ny proposal to provide needed telecommunication service, . . . shall be adopted only if commercial service is: a) not available to the user during the time needed; b) not adequate from either a technical or operational standpoint; or c) significantly more costly. NTIA Manual, supra note 7, Sec. 2.3.3.

allowing other criterion to prevail where spectrum is readily available.[41] NTIA allows each agency to determine what telecommunication systems meet cost-effectiveness and spectrum efficiency goals and mission requirements.[42] Oversight of individual agency programs for compliance with other Federal laws, Executive Orders or related executive branch directives has not been considered to be within the responsibilities of NTIA. Thus, agency decisions regarding use of commercial systems and efficiency and effectiveness are not ordinarily reviewed.[43]

Congressional Mandate

Congress inserted several provisions in the NTIAOA to help ensure more spectrum-efficient technologies for land mobile radiocommunication services. These provisions require NTIA to implement a plan for Federal agencies with existing mobile radio systems to use technologies that are at least as spectrum-efficient and cost-effective as readily available commercial mobile radio systems and provide a report to Congress by October 1, 1993, summarizing the plan. The specific provisions are listed in the BACKGROUND section of this report.

The NTIAOA also specifies that NTIA should promote efficient and cost-effective spectrum use for mobile radio services and provides NTIA explicit authority for withholding

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[41] Federal agencies are encouraged to use spectrum-conserving technologies and methods where they will satisfy agency operational requirements and will enhance service, economy of operation, and the more efficient and effective use of the radio spectrum. However, where spectrum is readily available due to geographic considerations or other factors, or where mission requirements mandate, security, economics, or some technical or system performance criterion may be the determining factor in system selection. NTIA Manual, supra note 7, Sec. 2.3.10.

[42] "Each Government agency decides, in the light of policies, rules, regulations, frequency allocations, and availability of frequencies, whether, what, and how mission requirements can be fulfilled by using telecommunication systems." NTIA Manual, supra note 7, Sec. 8.1.1.

[43] NTIA has instituted procedures in the Washington, DC area, where a commercially operated Government trunked system is available, that require agencies to justify new land mobile systems.

or refusing to assign frequencies to further those goals.[44] While calling explicit attention to regulation of mobile radio services, these provisions largely duplicate more general goals and authorities provided elsewhere in the Act.[45] The strong emphasis in the NTIAOA on NTIA regulatory powers regarding mobile services provides NTIA with firm guidance concerning regulation of the Government's use of mobile radio services.

OMB Regulations Affecting Acquisition of Telecommunication Services

OMB Circular No. A-76 establishes Federal policy regarding the performance of "commercial activities." "A commercial activity is one which is operated by a Federal executive agency and which provides a product or service which could be obtained from a commercial source. A commercial activity is not a Governmental function."[46] Although commercial activities are generally to be obtained from commercial sources, the Government can perform such an activity if either no commercial source is capable of providing the product or service, or use of such a source would cause an unacceptable delay or disruption of an essential program, or use of such a source would cost more.[47] A-76 requires that an Assistant Secretary or the equivalent in major component organizations be responsible for implementing

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[44] "In assigning frequencies for mobile radio services . . . , the Secretary of Commerce shall promote efficient and cost-effective use of the spectrum to the maximum extent feasible. . . . The Secretary of Commerce shall have the authority to withhold or refuse to assign frequencies for mobile radio service . . . in order to further the goal of making efficient and cost-effective use of the spectrum." NTIAOA, supra note 1, Sec. 104, para (d), (1)-(2).

[45] NTIAOA, supra note 1, Sec. 103, para (b) (2) (A).

[46] A-76, supra note 39., para 6.a.

On the other hand, "A Governmental function is a function so intimately related to the public interest as to mandate performance by Government employees. These functions include those activities which require either the exercise of discretion in applying Government authority or the use of value judgment in making decisions for the Government. Services or products in support of Governmental functions, such as those listed in Attachment A [of A-76], are commercial activities and are normally subject to this Circular." Ibid, para. 6.e.

[47] Ibid., para. 8.a. However, "Activities cannot be retained in-house if they are merely urgent, or support classified activities, or are required to perform an agency's basic mission." Ibid. Also, the Government can perform commercial activities involving the National Defense, under criteria established by the Secretary of Defense, or Patient Care. Ibid, para. 8.b.

its provisions and that this official approve certain justifications of Government performance of commercial activities.[48]

One way for NTIA to develop a "plan for Federal agencies . . . to use . . . technologies that are at least as spectrum-efficient and cost-effective as readily available commercial mobile radio systems," would be to include provisions for obtaining mobile services from commercial sources wherever technically and operationally feasible.[49] This would provide readily available commercial technologies directly to the Government agencies. However, competition and commercial services cannot always be relied upon to provide technologies that meet agency mission requirements and cost-effectiveness and spectrum efficiency goals. Thus, when commercial services are not available, regulations requiring the use of spectrum-efficient and cost-effective technologies to meet mission requirements must be developed.[50]

In most areas where a Federal agency requires land mobile communication services, there are no commercially available services capable of meeting agency requirements. In many of these cases, another Federal agency may be operating or may wish to operate a land mobile communication system. In these cases, agencies should be encouraged to share available other-agency services or combine resources to acquire a shared system.[51] Thus, an NTIA policy authorizing agencies to operate their own land mobile communication systems where commercial services are not available, or the use of such services would not meet requirements, would cause unacceptable delay or disruption, or would cost more would be appropriate with the intent of the NTIAOA and would not conflict with the requirements of A-76 for use of commercial sources. Furthermore, procedures requiring each agency to consider spectrum-efficient alternatives, including commercial service alternatives, for land

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[48] Ibid, para 9.a.

[49] The *House Report Filed on Spectrum Competitive Bidding and Spectrum Reallocation Legislation*, (House Report), U.S. Congress, House of Representatives, May 14, 1993, p 34 echoes this sentiment, as follows, "the Committee finds that some frequencies are assigned for services that could be obtained more efficiently from commercial carriers or other vendors."

[50] Agencies should be required to supply written justification when spectrum efficient technologies cannot be used.

[51] The provisions of the NTIA Manual already provide for and encourage this form of sharing, although as noted on page 55, NTIA has not heretofore reviewed these decisions. NTIA Manual, supra, note 7, Sec 8.2.48 Part 10.8.

mobile systems would be appropriate and within the intent of both the NTIAOA and OMB provisions.

POLICY CONCLUSIONS

1. The NTIAOA provides NTIA with explicit authority to regulate the Government's use of mobile radio services in such a way as to further the goal of making efficient and cost-effective use of the spectrum.

2. NTIA policy as expressed in the NTIA Manual, while strongly promoting spectrum-efficient technologies, use of commercially available technologies and interagency sharing of telecommunication resources does not mandate them. NTIA permits and encourages efficient systems and sharing between agencies and the use of commercial sector offerings, but NTIA does not require such systems and services or a showing of justification for not using such systems or services.

3. A-76 requires the use of commercial vendors to satisfy commercial activity requirements for the Government. However, it does permit agencies to perform commercial activities when there is no satisfactory commercial source available or using such a source would increase costs.

4. NTIA procedures requiring each agency to consider spectrum-efficient alternatives, including commercial service alternatives, for land mobile systems would be appropriate and within the intent of both the NTIAOA and OMB provisions.

POLICY RECOMMENDATIONS

In order to fulfill its mandates to "promote efficient and cost effective use of the spectrum to the maximum extent possible" and develop a "plan for Federal agencies . . . to use . . . technologies that are at least as spectrum-efficient and cost-effective as readily available commercial" land mobile radio systems, while minimizing long term costs and ensuring that agency mission requirements are satisfied, NTIA should implement policies that:

a. authorize agencies to operate their own land mobile systems where:

i. land mobile services offered by commercial vendors, including Specialized Mobile Radio (SMR) and other trunking systems, cellular radio systems, and "Personal Communication Services," are not available; or the use of such services would not meet requirements, would cause unacceptable delay or disruption, or would cost more;

ii. shared land mobile services offered by other agencies are not available, or the use of such services would not meet requirements, would cause unacceptable delay or disruption, or would cost more; and,

iii. land mobile services offered by State and local governments are not available, or the use of such services would not meet requirements, would cause unacceptable delay or disruption, or would cost more.

b. require the use of spectrum-efficient and cost-effective technologies to meet mission requirements where commercial services and service obtained from other agencies cannot be used.

c. withhold frequency assignments for Government land mobile radio stations that do not meet the goal of making efficient and cost-effective use of the spectrum.

APPENDIX: SPECTRUM EFFICIENCY OF TRUNKING SYSTEMS

SPECTRUM EFFICIENCY OF TRUNKING SYSTEMS

A primary advantage of trunking is its ability to significantly increase total traffic loading on individual channels and still provide a high probability of immediate access to users (i.e., a channel is available when needed). This is accomplished by spreading the statistical randomly occurring user requirements over a number of channels. Figure A-1, illustrating this advantage of trunking, plots the probability that an N-channel trunked system is not blocked (i.e., a channel is available) as a function of the loading (ρ) on individual channels.

The loading (ρ) refers to the percentage of time individual channels on a mobile system are occupied. The loading is directly proportional to the number of users on the system. Figure A-1 compares the probability of a user's access not being blocked for a single-channel (i.e., non-trunked system) with an N-channel trunked system when both systems have the same average loading per channel. (Figure A-1 is not a comparison of the advantage of using an N-channel system with a single channel non-trunked system where both systems have the same total traffic.)

Figure A-1 shows that for a single channel system (i.e., no trunking) the probability of not being blocked is linearly related to the channel loading. However, note that for trunked systems (N = 3, 5, 10, 20) the probability of blocking is not linearly related to the channel loading. This advantage of trunking systems derives from the statistical nature of mobile communications, which spreads channel congestion over more than one channel. From Figure A-1, with 50% loading on each channel ($\rho = 0.5$), the probability of not being blocked is 50% for a non-trunked system and 90% for a 5-channel trunked system. Note fromFigure A-1 that the advantage of trunking depends greatly on the loading factor ρ, and the number of channels.

Going further, from the data in Figure A-1, a comparison can be made of the relative spectrum efficiency of an N-channel system with a conventional single-channel system. The number of users is proportional to the loading and the ratio of loadings can be computed from the data in Figure A-1. As an example, for an 85% probability of non-blocking from Figure A-1:

$$\textit{Relative Spectrum Efficiency} = \frac{N_{trunked/channel}}{N_{non\text{-}trunked/channel}} = \frac{\rho_A(85\%,\ 5\text{-}channel)}{\rho_B(85\%,\ 1\text{-}channel)} = \frac{.523}{.1495} = 3.5$$

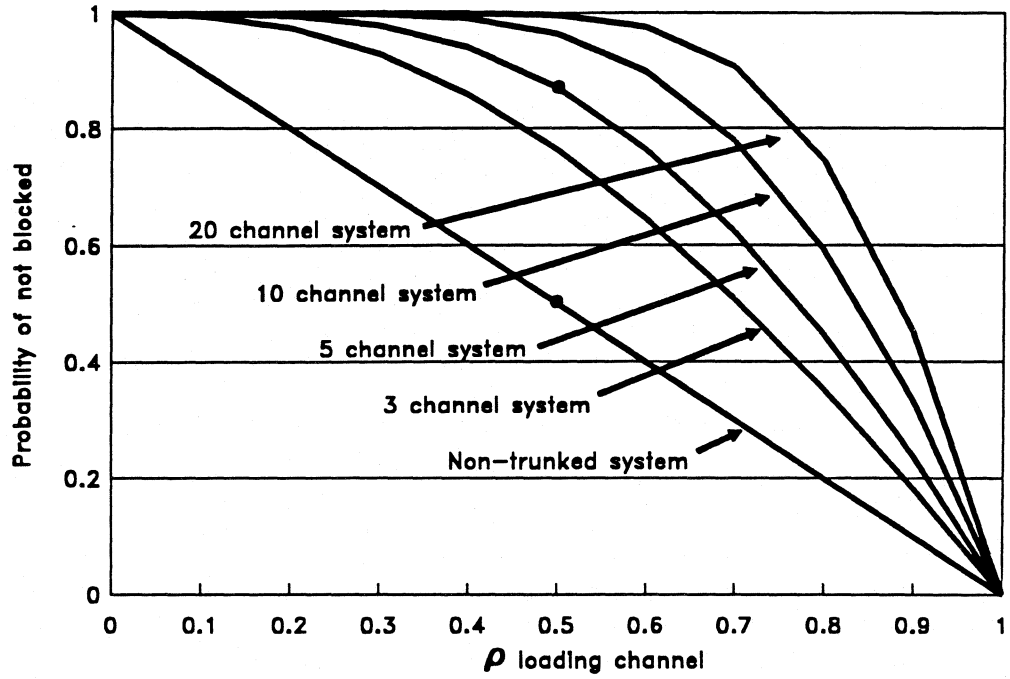

Figure A-1. Probability of access not being blocked for various systems with equal per-channel loading. The trunking characteristics assume a M/M/m queuing process without a control channel.[52]

Performing the same computation for the other data in Figure A-1 yields Figure A-2 which plots the spectral efficiencies of N-channel systems without a control channel to single-channel systems. The data in Figures A-1 and A-2 are only intended to illustrate the spectrum efficiency advantages of using trunking, and do not represent any one trunking system in particular.

[52] D. Bertsekas and Gallagher R., *M/M/m: The Server Case*, Data Networks, Section 3.4.1, p. 174-175, Prentice Hall, 1992.

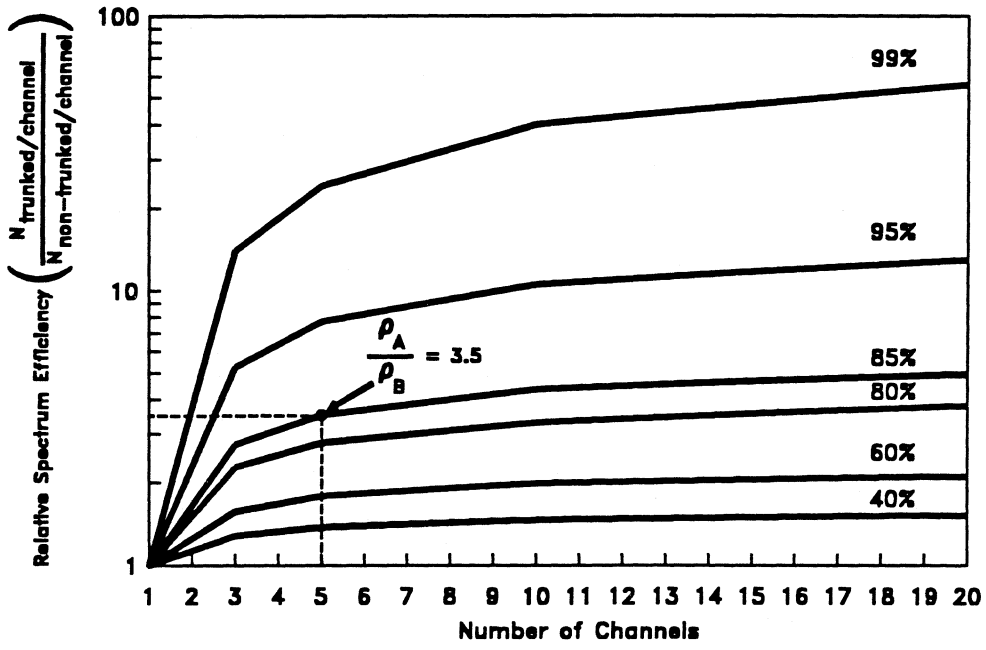

Figure A-2. Comparison of spectral efficiencies of N-channel systems without a control channel with single channel systems.

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The National Telecommunications and Information Administration (NTIA) in the fall of 1992 was required by Congress to develop and commence implementation of a plan for Federal agencies to use wireless mobile technologies that are spectrum efficient and cost effective. In response, NTIA performed an analysis of the current Federal land mobile infrastructure with respect to spectrum efficiency and cost effectiveness. This report documents the analysis, its results and conclusions, and an implementation plan with recommended milestones.

The report includes a summary of Federal land mobile requirements and techniques such as Simplex, Repeater, Trunking, Cellular, and Emerging Wireless Technologies. The benefits of rechannelization, trunking, and other technical methods to improve spectrum utilization are explained and their spectrum efficiency advantages are quantified. Methods to introduce cost effectiveness are also

(Continued)

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introduced. One of these methods is to exploit the economy of scope that exists, for example, if the cost of a single network is less than the cost of several individual networks. Policy and regulatory methods that NTIA could use to implement the plan presented in this report include Federal use of commercial vendor services (whenever feasible), and the use of shared systems among government agencies.