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TRANSPORTATION SYSTEMS CENTER

Spectrum Availability and
Digital Communication Links

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Summary of Proceedings

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These proceedings offer a summary of the seminar on Spectrum Availability and Digital Communication Links, held at the Volpe Center on August 20, 1996. They do not propose or advocate any specific views or actions, nor do they necessarily reflect the policies or views of the Department of Transportation or any of its elements.

Spectrum Availability and Digital Communication Links

I. Foreword

On October 26-27, 1995, more than 200 transportation leaders and decision makers from around the nation convened in Cambridge, Massachusetts, to participate in a two-day symposium on "Challenges and Opportunities for Global Transportation in the 2 1 st Century." The symposium was held at the John A. Volpe National Transportation Systems Center, or Volpe Center, which is part of the Research and Special Programs Administration of the U.S. Department of Transportation. The purpose of this event was to support effective public and private sector policy decisions by focusing on the core issues that underlie several of the most challenging transportation topics now on the national agenda.

As a follow-up to this event, the Volpe Center is conducting a series of six seminars in 1996 to explore in greater detail critical issues in transportation for the next century that were identified at the symposium. These six issues, and the dates for the seminars, are:

- "Emerging Issues in Transportation Information Infrastructure Security" (May 2 1).
- "Current and Future Federal Applications of Tagging and Tracking Technology" (June 18).
- "Mesoscale Weather Forecasting: Technological and Institutional Challenges" (July 16).
- "Spectrum Availability and Digital Communications Links" (August 20).
- "Travel and Tourism the World's Largest Industry: Transportation Challenges and Opportunities" (September 18).
- "Transportation Health Effects: A Current Assessment" (October 16).

Each seminar assembles approximately 40 to 50 public and private sector experts and transportation officials to provide in-depth focus on these important issues and identify potential areas where policy changes or further research and analysis may be required. This report summarizes the presentations and discussions that occurred during the fourth of these seminars, "Spectrum Availability and Digital Communication Links," which was held at the Volpe Center on August 20, 1996.

Proceedings for each of the six seminars will be made available in electronic format at http://www.volpe.dot.gov.

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III. Summary

The use of electromagnetic spectrum for transportation-related communications and radionavigation services plays a vital role in the provision of safe and efficient transportation. Although this use may not translate directly into monetary profit, vast industries such as aviation are entirely dependent upon these services, which are often provided by the federal government. There is currently tremendous demand for spectrum allocations for commercial organizations which provide consumer and business services. The federal government is responsible not only for balancing these wide-ranging public and private interests, but also for participating in international negotiations regarding spectrum management. To some participants in the seminar, transportation interests now appear to be at risk of being overshadowed by demand from other sectors, including a potential threat to public safety. Establishment of priorities for spectrum allocations for transportation will be increasingly important and contentious. Technology plays a prominent role in improving spectral efficiency, but can also increase demand for spectrum through the creation of new services and applications.

IV. Overview of the Issue

Radio transmission of information has long been utilized to improve the safety and efficiency of transportation system operations. Transportation applications of information technologies are generating a growing demand for wireless data communications--a need paralleled in other sectors. Radar sensing and radio navigation systems also play critical roles in transportation. The future availability of electromagnetic spectrum assignments is becoming a matter of serious concern, but the magnitude of the problem and the areas most likely to be affected are not well defined. These pressures have also increased interest in the potential to apply new, more spectrum-efficient technologies to transportation-related wireless data communications.

In the transportation sector, the need to communicate with moving vehicles places an obvious priority on wireless communications, as opposed to fixed wireline (cable and fiberoptic) alternatives. Various portions of the electromagnetic spectrum are being used for a wide range of services. Dedicated use of allocated spectrum is used for aviation navigation, positioning, and voice and data communications that are critical to the operation of the national and global air traffic control system. Wide-range two-way communications are used to dispatch fire and police vehicles, commercial trucks, taxis, and public transit vehicles. The railroad industry depends on the Railroad Radio Service to provide voice and data communications for critical railroad safety functions. Maritime spectrum allocations not only support critical radiolocation and radionavigation services, but also provide channels used for routine communications, distress response, and search and rescue. Space transportation facilities require spectrum assignments for launch vehicle communications and telemetry, tracking and control functions.

Technical considerations greatly limit the spectrum "window" which is practical for various purposes. At very low frequencies, unwieldy antennas are required. At very high frequencies, propagation characteristics can limit the distance or path over which signals can be effectively transmitted, and system components can become more expensive. In some applications, existing allocations for wireless transportation communications are already marginally adequate, and competition for spectrum segments is becoming intense. Wireless systems currently represent the most rapidly expanding part of the telecommunications industry. The transportation community, both public- and private-sector, faces many challenging situations in achieving and adapting to an equitable distribution of available spectrum assignments.

There are many technical complexities to this topic. Assessment of the feasibility and relative attractiveness of alternative frequencies for a particular function is a complex process often dependent on the potential for interference from other users, sometimes including spurious signals and harmonics from other frequency bands. The ongoing development of advanced technologies, in particular a shift from analog to digital communications, will play a critical role in improving spectral efficiency. However, these improvements are accompanied by increasing demand for spectrum to meet the communications needs of a rapidly growing market for a wide array of non-transportation functions--a market that is fueled in part by technological developments and associated cost reductions.

The institutional and administrative aspect of spectrum allocation is similarly complex. The Federal Communications Commission (FCC) is responsible for assignments for all non-Federal users, with the National Telecommunications and Information Administration responsible for Federal uses. International coordination is a clear necessity, and a framework for such coordination is provided by the International Telecommunication Union (ITU), an arm of the United Nations. ITU's radio regulations have treaty status, and the process for development of these regulations is lengthy. Spectrum planning for aviation and maritime applications, for example, can consequently have a 5-10 year horizon.

The task these agencies face is daunting. FCC and NTIA must achieve an acceptable and equitable allocation among many vitally-interested claimants and users of this limited resource, which has great commercial value as well as importance to the public sector. They must also be sufficiently prescient and technically proficient to provide a spectrum framework that can accommodate future expansion and the emergence of applications and levels of demand not yet envisioned. As a measure of the uncertainties in this area, it is noteworthy that in 1983 industry analysts predicted one million American users of cellular services in 2000; the total already exceeds 20 million. Projected growth rates range from 50% in the US to 200% in some South American markets.

Increased demand for new and expanded allocations, and awareness of the economic value of these assignments, is embodied in the ongoing process of deregulation of the telecommunications industry. Assignments within some spectrum bands are now being determined by FCC-run auctions, and some Federal bands are being redefined for private-sector use. The economic value of spectrum is evident in the $9 billion already received through five recent auctions. However, many current and potential users of spectrum do not use it to generate income, but rather to provide functions with important benefits to the public. Examples include public safety, transportation applications, amateur radio, and radio astronomy. This raises important questions regarding how spectrum is valued.

Thus, there is continued pressure to reallocate spectrum from Federal use to the FCC for private use, and to accommodate an increasing number of users with the same amount of spectrum. For example, crowding of the private land mobile radio (PLMR) bands below 800 MHz has prompted the FCC to enable increased use of these bands through the application of more spectrally efficient technologies, and by introducing market forces into the allocation process.

Spectral capacity will be increased, in part, through "refarming" of current channels into progressively narrower bandwidths. As an example, the FAA has reduced channel bandwidths for air-ground voice communications by a factor of eight since the 1950's, and anticipates another factor of four reduction by 2003. Options for applying economic incentives include exclusivity, user fees, and competitive bidding. In response to Title VI of the Omnibus Budget Reconciliation Act (OBRA) of 1993,235 MHz of spectrum has been identified for transfer from the Federal government to the private sector.

This transfer is not without cost. It has been estimated that reallocation costs to the Department of Transportation alone to redesign air traffic control radar software, add filters to existing radars, and replace fixed microwave links could exceed $100 million. Transit and railroad users are similarly concerned about the costs of shifting to alternative assignments.

Such pressures have focused attention on the policy debate regarding the provision of services that benefit society but may not be well-matched to "normal" market operation. For example, the PLMR bands have historically accommodated communications associated with the operation of railroads and transit systems, as well as public safety and law enforcement agencies--services that provide great benefits and have significant safety implications, but also that may not be well-positioned to raise the capital potentially required to participate successfully in an open auction of spectrum. The American public clearly expects and insists that safety and security not be hampered by deficiencies in communications systems.

However, many of the wireless communications systems that have been in operation for many years are based on spectrally-inefficient technologies, and society could realize significant economic benefits from the increased availability of spectrum that would result from a shift to more efficient technologies. At the same time, these systems represent significant "stranded" investments, and there are strong pressures to continue operating them as long as possible.

V. Topic 1: Transportation Requirements

(a) Background

Although communications requirements in the transportation sector are, on a general level, similar to those of other users of communication services, the relative importance of different requirements can vary greatly. Participants at the Volpe Center symposium identified six key areas for transportation:

Capacity--The data transmission rates (bandwidth) associated with different transportation communications services vary greatly. Some applications, such as video feeds from remote cameras for transportation monitoring or other real-time sensing could be associated with very large continuous data loads requiring substantial bandwidth. Capacity shortfalls in transportation systems manifest themselves as delays or momentary loss of information for users, and the same is true for communication systems. Constrained data transmission rates and associated limits on availability of services can seriously hinder operations, entailing economic losses in most cases and sometimes endangering human life.

Affordability--Cost issues are important both to users of transportation communications systems and to those responsible for establishing and maintaining these systems. This includes not only the cost of any communications equipment, but also any and all associated operational and maintenance costs.

Availability--Long-range, large-area coverage is necessary for many applications. Data communications supporting air and water transportation often require international coverage.

Interoperability--Transportation applications often involve many parties--public agencies, service providers, shippers, the general public and other users. Some systems are inherently regional, national or global, and others must at least accommodate user systems on vehicles arriving from other localities. A high degree of interoperability is required for successful realization of many promising system concepts, necessitating broad standard-setting efforts and the establishment of institutional cooperation. Commonality of operational frequencies is a virtually necessity in achieving interoperability.

Reliability--Some transportation functions require a very high level of integrity and reliability. Examples include vehicle-to-vehicle data links used for crash avoidance, and vehicle positioning for aircraft, trains, and ships. For other functions, such as automatic toll collection and pre-trip route planning, integrity and reliability are less critical, but still important for operational efficiency and user acceptability.

Maintainability--Although some transportation system operators have the technical capacity to maintain communications equipment for which they are responsible, equipment that requires a great deal of attention may not be well received by users that lack such abilities.

General requirements are reasonably well characterized for transportation-related wireless communication currently in widespread use. However, even for these activities, requirements are not static, and increases in travel demand are placing corresponding pressures on capacity. Implementation of intelligent transportation system (ITS) functions will lead to the provision of new services that, in many cases, rely heavily upon wireless communications. These include such diverse functionalities as traveler information services and longer-range two-way data communications that might rely on systems which are not transportation specific (e.g., Cellular Digital Packet Data), and automated toll-collection.

Transit data loads and communications requirements could be greatly increased by advanced traveler information systems--for example, dynamically-dispatched paratransit would be heavily reliant upon significantly improved and less expensive data communications and computing capacity. Positive Train Control could similarly alter demands and technical requirements for railroad-related data communications. A shift to free flight would dramatically alter aviation-related communications demands and requirements. The expanded use and performance of the Global Positioning System is critically dependent on the adequacy and freedom from interference in its dedicated frequencies. In all of these service areas, it is critical to understand both the magnitude and character of the implied data communications requirements.

(b) Discussion

Participants noted that different users in the transportation sector will rank requirements differently. For example, truck drivers, who travel across many states, will be particularly sensitive to interoperability, and will strongly prefer to be able to use a single toll tag in more than one area. On the other hand, private individuals--likely to do most of their driving in a more limited area--may be willing to switch back to the use of cash for occasional long trips on distant toll roads. Interoperability, reliability, availability, and capacity will be crucial for mayday services, but affordability will be more important for conveniences such as traveler information services.

It was noted during these discussions that the relative importance of such requirements has an impact on spectrum needs. Capacity is a key factor in bandwidth, and hence spectrum, needs. Reliability and availability affects the selection of frequency bands. Interoperability, affordability, and maintainability all influence both the frequency bands and the overall spectrum required.

A substantial portion of the discussion concerned the sensitivity and importance of safety-related communications in the transportation sector. For example, reliability limitations associated with the very low level of the GPS signal may merely be inconvenient for some GPS users, but could be‘of great importance to FAA and the aviation industry. Similarly, priority access is critical in the marine environment, in order to ensure that rescue teams can respond quickly in emergencies--the same need that exists for land-based emergency response services. Although many transportation applications are officially classified as “public safety” functions, reliable communications also play a pivotal role in preventing transportation accidents.

VI. Topic 2: Communications Technology

(a) Background

The number of technological options available for wireless data exchange continues to grow very rapidly. Several new techniques offer significant improvements in spectrum efficiency. On the other hand, some of these have not yet evolved into open standards, and it may be difficult to reliably predict the number of users and associated deployment and utilization costs. At the same time, more accepted systems, although they may offer attractive economies of scale, could have transitional difficulties with peak flow accommodation that cause concern for certain transportation applications.

In selecting technologies to fill wireless data requirements for transportation, system designers can expect to face many options that defy easy characterization and differentiation, although the field may be reduced as alternative systems are tested in the marketplace. Many land-based techniques are currently being proposed for bi-directional data exchange, and a variety of satellite-based communication systems are currently being developed by the private sector.

There is also a wide range of choices being offered for broadcast-only, wide-area wireless data transfer, for applications such as weather and traffic advisory services. Passive or active radio-frequency and infrared transponders are all potentially useful for short-range (vehicle-to-roadside) communications and sensing. For all communications except vehicle-to-vehicle links, design choices often exist between the use of wireless and wireline infrastructure as the communication backbone.

The National ITS Architecture Communications Document provides a detailed assessment of many wireless and wireline communications technologies, and suggests a process for selecting among them on the basis of local requirements. However, the increasingly wide-ranging and complex array of options will pose a significant challenge to system planners responsible for deciding how wireless systems for transportation should be designed and on what schedules they should be deployed.

(b) Discussion

With respect to current transportation communications systems, participants discussed the availability of technology improvements to improve spectral efficiency of current transportation-related communications. FAA, for example, plans to employ new modulation techniques such as Time Division Multiple Access (TDMA) to achieve further spectral efficiencies in air-ground voice communications, as noted above. FAA has also increased the channel capacity of the 108-1 18 MHz band for navigational aids from 100 to 200 channels by going to 50 kHz channel spacing. Such shifts to narrower bandwidths place more stringent requirements on receivers, and several participants noted that while NTIA regulates receiver performance in order to improve spectral efficiency of Federal applications, privately operated receivers are not regulated by the FCC.

Panelists and participants also discussed technology options for emerging transportation applications such as ITS. An extremely wide range of options are available for some of these applications. For example, telephone directory services could be provided by cellular access to intemet providers, by a periodically updated on-board CD-ROM, or by an on-board database which is continually updated through a slow, narrow bandwidth data broadcast service. Choices among options, and standardization of those choices, will determine both the ability to meet the multiple demands of transportation system users, and the amount of spectrum that will be required to do so.

One panelist also discussed the fact that even for what are considered by most to be “emerging” applications, systems supporting these applications (e.g., electronic toll collection) already exist in some areas. This increases the importance of the “migration path” leading from an array of existing systems to eventual standardized systems. One technological option that may ease such transitions could be a “software radio” that can transmit and receive in a flexible manner matched to current requirements--a simple example would be a telephone that selects either a satellite or cellular link, based on availability and cost. This panelist also suggested that such an approach might even be eventually extended to the allocation of spectrum, such that spectrum is provided “on demand” as needed for specific requirements (e.g., data rate) at specific instants in time.

VII. Topic 3: Spectrum Management

(a) Background

Transportation applications such as air traffic control, transit system communications, and railroad dispatching have relied for many years on specific spectrum assignments set aside for these purposes. For some of these applications, recent and/or projected volumes, and new operational demands, already present a serious challenge to available capacity.

On the other hand, the private sector places a high and increasing monetary value on spectrum access. This has created significant pressure to use all spectrum as efficiently as possible. Although capacity still exists in the higher frequency bands and can be utilized for some applications, technical limits such as propagation characteristics, weather effects, and availability of reasonably-priced equipment limit their use. More spectrum-efficient technologies can be an important strategy-one which is assumed by policy shifts such as reallocation (from federal to non-federal use) and reducing channel bandwidth. It has been estimated that Time- and Code-Division Multiple Access techniques, for example, can increase the capacity of existing land mobile systems by as much as twenty-fold.

At the same time, budgetary constraints may be such that there are also major pressures to extend the service life of existing equipment as much as possible. Transportation system operators vary in ability to pay for the ongoing and, in particular, the up-front costs associated with wireless communications systems and technological transitions. In some cases, agencies are constrained both in terms of projected tax-based funding, and in the ability to pass along communications costs to customers. Generally, public agencies are not in a strong position to compete in spectrum auctions, even though they may ultimately find themselves leasing capacity from the winners.

Because some transportation-related wireless data communications services are or will be critical from the standpoints of safety and access, important policy issues need to be addressed in decisions regarding the availability and cost of access to needed spectrum assignments. The societal goal of providing safe, convenient, and affordable transportation will continue to create associated wireless communications requirements, and these must be taken into account when pursuing economic growth through increased spectral efficiency and availability.

(b) Discussion

Most attendees expressed the view that the current structure (i.e., NTIA management of Federal spectrum use, FCC management of non-Federal use) for spectrum management in the U.S. provides a balance of fundamental missions and philosophies. Several panelists expressed concern that if NTIA were to be dismantled, as is currently under consideration, this balance between public and private valuation of spectrum would be lost. On the other hand, it was noted that the FCC already manages spectrum used by many public providers (e.g., fire departments, ambulances, transit dispatchers), and has a regulatory process that is open and responsive to public comment, and increasingly accessible with the advent of the World Wide Web.

There was considerable discussion of the continued pressure to reallocate spectrum from Federal to non-Federal users, and several participants expressed concern that any further reallocation would be much more difficult to accommodate than the first 235 MHz under the Omnibus Budget Reconciliation Act (OBRA) of 1993. A number of panelists expressed concern with the rapid move toward auctioning of emission rights and interference protection related to non-Federal spectrum utilization, and it was noted that the current auctioning process does not use the revenues generated from auctions to pay for expenses incurred by existing users. On the other hand, some participants suggested that it might be appropriate to broaden auctioning to cover all or nearly all non-Federal spectrum including, for example, television broadcast channels. Several panelists also stressed the importance of international aspects of spectrum management--although looser geographical constraints in the U.S. allow flexibility in many bands, caution may be important to ensure global interoperability and marketability of U.S. products.

With respect to use of transportation utilization of spectrum, there was considerable discussion of the importance of timely identification of priorities. It was noted that while the telecommunications industry and other commercial users are able to define requirements quickly, Federal agencies typically have a much slower process for identifying needs. As a result, spectrum may be allocated for commercial purposes before Federal users have even submitted a request.

As is discussed above, this longer process is, in many ways, the result of essential international harmonization. In addition, one presenter pointed out that there is a need for prioritization even within the transportation sector. For example, FCC recently made several millimeter-wave bands available for the development of automotive radars, but is now reviewing comments by the FAA regarding potential interference (by radiation in the second harmonic) with aircraft imaging systems. The transportation community was encouraged to “speak up now or forever be silent,” and to be specific about the frequency, time, and geographic extent of these requirements.

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