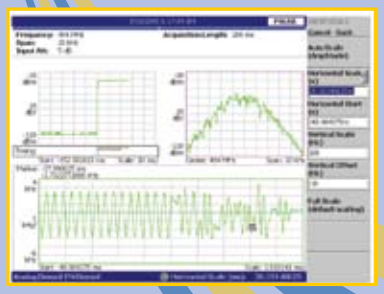



Institute for Telecommunication Sciences

2005

TECHNICAL PROGRESS REPORT




U.S. DEPARTMENT OF COMMERCE
NTIA
NATIONAL TELECOMMUNICATIONS & INFORMATION ADMINISTRATION

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Institute for Telecommunication Sciences

2005 Technical Progress Report

U.S. Department of Commerce
Carlos M. Gutierrez, Secretary

Michael D. Gallagher, Assistant Secretary
for Communications and Information

January 2006

Certain commercial equipment, components, and software are identified in this report to adequately describe the design and conduct of the research and experiments at ITS. In no case does such identification imply recommendation or endorsement by the National Telecommunications and Information Administration, nor does it imply that the equipment, components, or software identified is necessarily the best available for the particular application or use.

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An ITS engineer operates a custom-designed radar transmitter during tests of a prototype 5 GHz dynamic frequency selection (DFS) device at the ITS laboratory (photograph by F.H. Sanders).

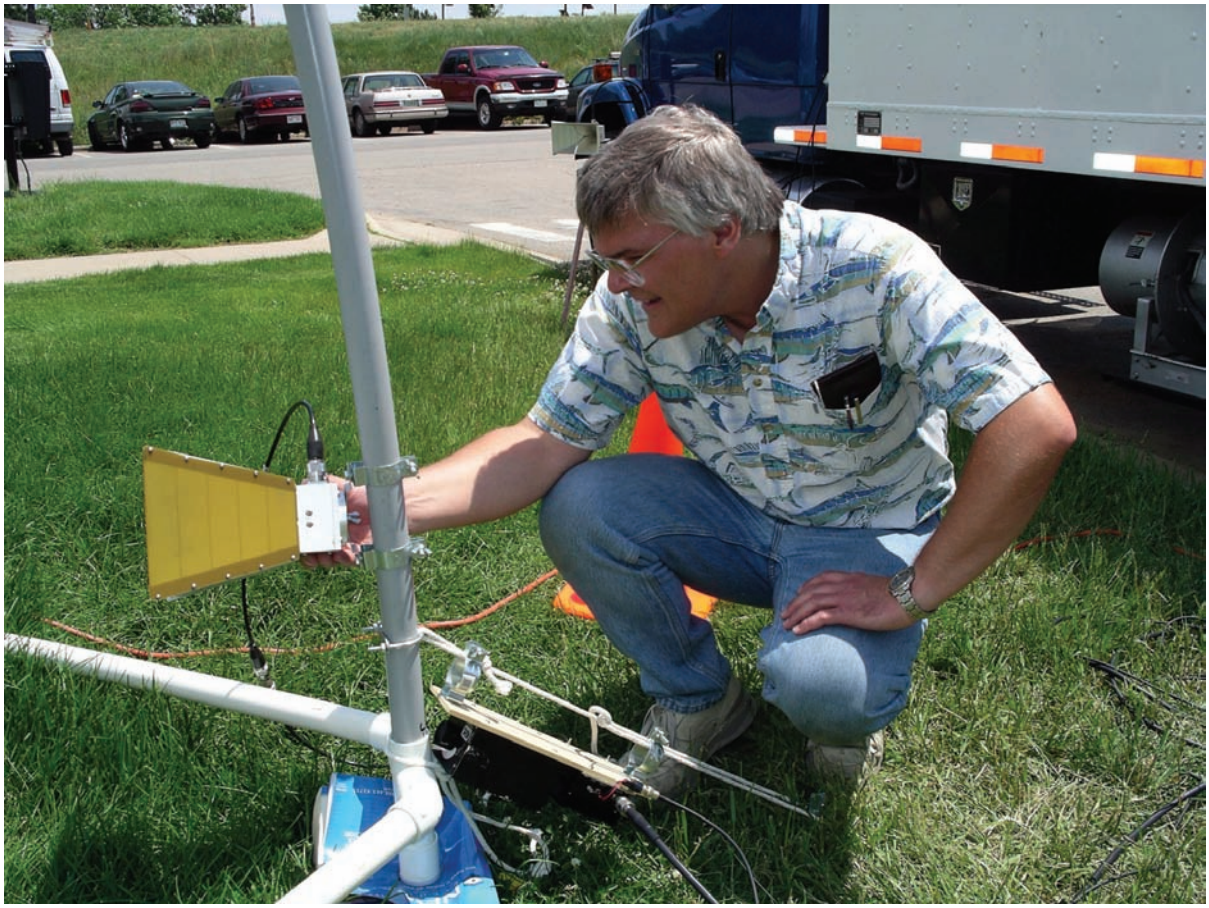
The ITS Mission

The Institute for Telecommunication Sciences (ITS) is the research and engineering laboratory of the National Telecommunications and Information Administration (NTIA). ITS provides technical support to NTIA in advancing telecommunications and information infrastructure development, enhancing domestic competition, improving U.S. telecommunications trade opportunities, and promoting more efficient and effective use of the radio spectrum.

ITS also serves as a principal Federal resource for solving the telecommunications challenges of other Federal agencies, State and local governments, private corporations and associations, and international organizations.

ITS supports private sector telecommunications activities through cooperative research and development agreements (CRADAs) based on the Federal Technology Transfer Act of 1986. The Act encourages sharing of Government facilities and expertise as an aid in the commercialization of new products and services. ITS is a member of the Federal Laboratory Consortium for Technology Transfer, formally chartered by the Act in 1986.

ITS provides leadership and technical contributions in national and international telecommunication standards committees under OMB Circular A-119, which provides ground rules and encouragement for Federal agency involvement in voluntary consensus standards development.



An ITS engineer prepares a calibrated horn antenna for use in outdoor measurements of the emissions produced by a satellite telephone (photograph by F.H. Sanders).

Overview

The Institute for Telecommunication Sciences (ITS), located in Boulder, Colorado, is the research and engineering arm of the National Telecommunications and Information Administration (NTIA), of the U.S. Department of Commerce (DOC). The Institute's staff of Federal employees provides strong engineering and scientific skills and experience to our technical programs. The majority of employees are electronics engineers, but the staff also includes mathematicians, physicists, computer scientists, and specialists in other fields. ITS' support during Fiscal Year 2005 consisted of $6 million of direct funding from the DOC and approximately $8 million for work sponsored by other Federal agencies and U.S. industry.

History

ITS began in the 1940s as the Interservice Radio Propagation Laboratory, which after the war became the Central Radio Propagation Laboratory (CRPL) of the National Bureau of Standards, Department of Commerce. A new facility was built for CRPL in Boulder and dedicated by President Eisenhower in September, 1954.

In 1965, CRPL joined the Environmental Science Services Administration and was renamed the Institute for Telecommunication Sciences and Aeronomy (ITSA). In 1967, ITSA split into two labs: the Aeronomy Laboratory and the Institute for Telecommunication Sciences (ITS). In 1970, Executive Order 11556 established the Office of Telecommunications (OT) within the DOC and the Office of Telecommunications Policy (OTP) in the Executive Office of the President; at the same time, ITS was transferred to OT. Under the President's Reorganization Act #1 of 1977, OT and OTP merged to form NTIA.

Since 1978, ITS has performed telecommunications research and provided technical engineering support to NTIA, and to other Federal agencies on a reimbursable basis. Over the last 15 years, ITS has pursued cooperative research with U.S. industry under the provisions of the Federal Technology Transfer Act of 1986.

Our Expertise

- **Radio Research Fundamentals and Spectrum Measurement:** ITS measures emission characteristics of Federal transmitter systems, and identifies and resolves radio frequency interference. We incorporate remote sensing data into our signal propagation models, and explore advanced antenna designs.
- **Communication Systems and Networks:** ITS plans, implements, and evaluates telecommunication systems.
- **Public Safety Interoperability:** ITS facilitates interconnectivity and interoperability between services and technologies.
- **Standards Development:** ITS has a long record of leadership and technical contributions to telecommunication standards committees.
- **Wireless Voice/Data Systems and Emerging Technologies:** ITS assesses telecommunications system components, evaluates network survivability, and assesses system effectiveness in national security/emergency preparedness, military, and commercial environments. We test emerging technologies, e.g., Voice over IP and ultrawideband.
- **Audio and Video Quality Research:** For over 15 years, ITS has conducted research on digital audio and video quality, grounded in signal processing theory and models of perception.
- **Electromagnetic Modeling & Analysis:** ITS maintains ongoing investigations in broadband wireless systems performance, propagation model development, advanced antenna designs, and noise as a limiting factor for advanced communication systems.

Our Facilities

The Institute's world-class facilities include:

- **Audio-Visual Laboratories**
- **Interoperability Research Laboratory**
- **Radio Spectrum Measurement Science (RSMS)**
- **Secure Internet (SIPRNET)**
- **Table Mountain Field Site/Radio Quiet Zone**
- **Telecommunications Analysis Services**
- **Wireless Networks Research Center**

The Benefits Created by ITS

The Institute's research significantly benefits both the public and private sectors in several areas:

- **Spectrum Utilization:** Optimization of Federal spectrum allocation methods, identification of unused frequencies and potential interference through field measurements, and promotion of technology advances to aid in efficient use of the spectrum.
- **Telecommunications Negotiations:** Expert technical leadership at international conferences and development of negotiation support tools such as interference prediction programs.
- **Public Safety:** Systems engineering, planning, and testing of interoperable radio systems (e.g., voice, video, and data) for the use of "first responders" at the Federal, State, local, and tribal levels.
- **National Defense:** Improvement of network operation and management, enhancement of survivability, expansion of network interconnections and interoperation, and improvement of emergency communications that contribute to the strength and cost-effectiveness of the U.S. Armed Forces.
- **Domestic Competition:** Development of user-oriented, technology-independent methods of measuring telecommunications performance to give users a practical way of comparing competing equipment and services.
- **International Trade:** Promulgation of international telecommunications standards to remove technical barriers to U.S. export of telecommunications equipment and services.
- **Technology Transfer:** Direct transfer of research results and measurements to U.S. industry and Government to support national and international competitiveness, bring new technology to users, and expand the capabilities of national and global telecommunications infrastructures.

Our Organization

The Institute's technical activities are organized into four program areas:

- **Spectrum and Propagation Measurements**
- **Telecommunications and Information Technology Planning**
- **Telecommunications Engineering, Analysis, and Modeling**
- **Telecommunications Theory**

ITS's research and engineering work is supported by the Director's Office, which provides support to the program, budget, and administrative functions of the Institute. ITS also maintains an NTIA liaison function to provide assistance to NTIA on participation in national and international conferences and negotiations. The liaison also coordinates the laboratory's technical research with other Federal agencies.

Our Sponsors

Activities at the Institute are undertaken through a combination of programs sponsored by the Department of Commerce and other Federal agencies, and through cooperative research agreements with the private sector. The Institute's policy stipulates that research sponsored by other agencies must contribute to and reinforce NTIA's overall program and must be directed toward supporting the goals of the Department of Commerce. Major other agency sponsors include the National Institute of Standards and Technology's Office of Law Enforcement Standards, the Department of Homeland Security, the Department of Transportation, the National Weather Service, and the U.S. Coast Guard.

Cooperative research and development agreements (CRADAs) with telecommunication-operating companies and manufacturers support technology transfer and commercialization of telecommunications products and services, which are major goals of the Department of Commerce. ITS has CRADAs with large established companies as well as small, start-up companies. Partnerships such as these enhance synergies between entrepreneurial ventures and broad national goals.

Because of its centralized Federal role, ITS can provide a cost-effective, expert resource that supports many Federal agencies and industry organizations. ITS provides research and engineering that is critical to continued U.S. leadership in providing telecommunications and information equipment and services. This Progress Report summarizes technical contributions made by ITS during Fiscal Year 2005 to both the public and private sectors.

Radio Spectrum Measurement Science (RSMS) truck on site for the Land Mobile Radio measurements in Washington, DC (photograph by I.L. Tobias).

Spectrum and Propagation Measurements

The radio spectrum is an enigmatic natural resource that offers immense benefit to industry, government, and private citizens by supporting radio/wireless communications and a wide variety of other systems like radar and remote sensing. It is non-depleting and exists everywhere, but it is finite and can be rendered less useful by noise and interference. Until recently, traditional methods of allocating spectrum and assigning channels have ensured effective and efficient use of the spectrum. Today, the rapidly expanding competition for spectrum use and the plethora of new signal types and applications have created an apparent shortage of radio spectrum. While new spectrum management methods will alleviate this problem, they cannot do so without increasingly more complex knowledge of the existing signals and noise environment and better understanding of how systems that share spectrum affect each other.

The Spectrum and Propagation Measurements Division provides the technical information needed to enable more effective and efficient use of the spectrum, thus enabling spectrum allocation and sharing regulations and policies that are effective, reliable, and enduring. To do so, the division performs analyses and measurements of the effects of radio signals on the spectrum and on other systems. Measurements and assessments of spectrum occupancy can be accomplished at any location using the mobile Radio Spectrum Measurement Science system. New measurement methods are developed and complex testing is accomplished in well-equipped laboratories and at the Table Mountain Field Site.

The following areas of emphasis are indicative of the work done in the Division recently in support of NTIA, other Federal Agencies, academia, and private industry.

Areas of Emphasis

Radio Spectrum Measurement Science (RSMS) Operations
The RSMS is comprised of laboratory, transportable, and mobile facilities. This capability is used to assess spectrum occupancy and usage, electromagnetic compatibility, and to resolve interference problems. This project is funded by NTIA.

RSMS-4 Development
Measurement methods, both established and new, are supported by hardware and software. They are continually being refined and developed. The fourth generation system software is capable of fully autonomous operation and remote monitoring, uniform data recording and storage, and powerful analysis and display routines. This project is funded by NTIA.

Table Mountain Research Program
This field site, protected by state law and federal regulation as a radio quiet zone, is used by many operations and experiments that require both protection from strong, external radio signals, and minimum vibration. Research into new spectrum occupancy measurement methods, including radio noise measurement, new antennas, and complex radar measurements are conducted by ITS at the site. These projects are funded by NTIA.

Spectrum Efficiency Research and Engineering
Investigations of the efficient and effective use of the radio spectrum, including allocation and assignment methods, are pursued. Definitions for spectrum efficiency and effectiveness can be nontrivial and elusive. Actual measurements of band and channel usage are compared with known assignments to determine the merits of new and competing channel assignment schemes. This project is funded by NTIA.

Signal Characteristics, Spectral Emissions, and Interference Analyses
A complex assessment of the interference potential of ultrawideband (UWB) signals was largely completed this past year. This study required the utmost care and thoroughness to determine which characteristics of a variety of UWB signals were best correlated with interference effects observed in a digital television satellite receiver. This project is funded by Freescale, Inc.

Radio Spectrum Measurement Science (RSMS) Operations

Outputs

- Measurements to determine move-times, detection thresholds, and aggregate emission characteristics of dynamic frequency selection (DFS) devices.
- Measurements and report on Land Mobile Radio (LMR) channel occupancy in Federal bands 162-174 MHz and 406-420 MHz.
- Measurements to address compatibility between radiolocation and maritime and aeronautical services in the bands 9000-9200 MHz and 9300-9500 MHz.

The Radio Spectrum Measurement Science (RSMS) Operations project performs critically needed radio signal measurements necessary for making decisions regarding Federal Government spectrum allocations. As stated under Departmental Organization Order 25-7, issued 5 October 1992, and amended December 1993, the NTIA Office of Spectrum Management (OSM) is responsible for identifying and making arrangements for measurements necessary to provide NTIA and the various departments and agencies with information to ensure effective and efficient use of the spectrum. The RSMS resides at ITS and is tasked to perform measurements in support of OSM as required to fulfill their mission. ITS, through the RSMS Operations program, provides OSM and the executive branch with radio spectrum data, data analysis, reports, and summaries. The four basic areas of RSMS are 1) spectrum surveys and channel usage, 2) equipment characteristics and compliance, 3) interference resolution and compatibility and 4) signal coverage and quality. In FY 2005, several different measurements were performed in support of the basic mission.

In August 2005, additional laboratory measurements were conducted to determine move-times and detection thresholds of dynamic frequency selection (DFS) devices. DFS is a method whereby a radio-local-area-network (RLAN) device, using the 5-GHz band for unlicensed operations, will detect the operations of radar and promptly evacuate the channel if the radar is present. Measurements were conducted to determine if current DFS devices comply with specifications given in ITU-R M.1658. In FY 2004, testing was performed to demonstrate DFS proof of concept with a table of radar signals developed in conjunction with the Federal Communications Commission (FCC), industry, the Department of Defense (DoD), and NTIA. In FY 2005, additional testing was performed with a new set of radar signals developed by the DoD and NTIA to ensure radar operations in the 5-GHz band were protected. The test results will help determine whether this technology is able to move forward toward deployment in commercially available RLAN-type communication devices. In preparation for radiated measurements scheduled for FY 2006 to determine degradation of radar capabilities, aggregate radiated emissions of multiple DFS devices were also recorded at the Table Mountain facility located north of Boulder, Colorado, for the purpose of modeling these signals.

In the early part of FY 2005, measurements were conducted in the Washington, DC, area to measure and provide a report on Land Mobile Radio (LMR) channel occupancy in Federal bands 162-174 MHz and 406-420 MHz. This was part of NTIA's effort to improve the spectrum efficiency of Federal radio usage. Specifically, this effort was undertaken to help obtain data required to realistically design future possible shared trunked systems for Federal radio users and determine long-term usage trends by comparing results with previous measurements taken in the same location in 1986 and 1989. The measurements were made using new equipment and techniques developed at ITS that measure large areas of the spectrum and process it to obtain simultaneous signal levels of up to 480 individual LMR channels. These techniques provided faster measurements, but also allowed enhanced post-processing of the data to remove measurement defects.

In support of an agenda item at the International Telecommunication Union - Radiocommunication Sector's (ITU-R) World Radiocommunication Conference (WRC-07) to upgrade the status of the radiolocation service in the bands 9000-9200 MHz and 9300-9500 MHz to primary status, measurements were conducted in April of FY 2005. The

RSMS truck on site for the Land Mobile Radio measurements in Washington D.C. (photograph by I.L. Tobias).

measurements were designed to address compatibility between radiolocation and maritime and aeronautical services in the above mentioned bands. Waveforms of the radiolocation systems were generated and injected into the receiver of an SPS-73 radionavigation system to determine levels of degradation.

In support of a current review by NTIA/OSM of a spectrum support request that is contingent upon the in-band and out-of-band emissions of a Globalstar Mobile Satellite Service, measurements were made in late FY 2005 to characterize the emission levels of these devices. In addition, similar measurements were conducted to characterize emissions of a 1.9-GHz cellular handset. Of particular interest were the out-of-band levels received in the global positioning system (GPS) bands.

To investigate waiver applications to the FCC's ultrawideband Part 15 Rules permitting devices to employ swept frequency techniques, measurements were conducted at the ITS Boulder Labs. The purpose was to provide an understanding of swept signals at the output of various filter bandwidths and to provide information to develop test procedures that could be used in compliance measurements.

In support of the ITU-R Joint Rapporteurs Group 1A/1C/8B regarding the international review of emission limits of radar systems, measurements were conducted in October of FY 2005 on several Japanese radars. The purpose was to collect emission characteristics to help with decisions in the development of the ITU limits which currently are similar to specifications stated in the U.S. Radar Spectrum Engineering Criteria (RSEC).

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Radio Spectrum Measurement Science (RSMS)-4 Development

Outputs

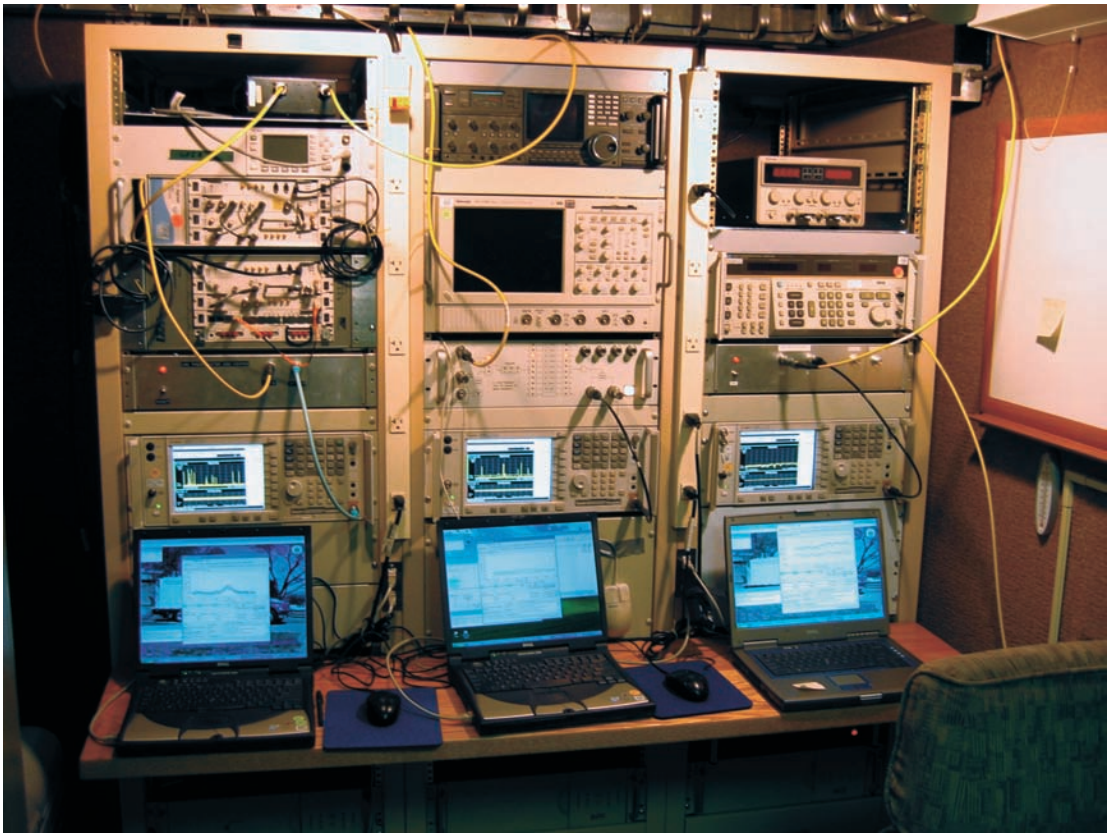
- Two new ITS custom-built preselectors and enhancements of existing preselectors.
- Real-time fully automated direction-finding system that can be used with pulsed signals such as radar.
- Fully automated data acquisition and processing software used for Land Mobile Radio channel occupancy measurements.
- Several new ITS custom-designed software modules for instrument control and measurement.

The 4th generation system for the Radio Spectrum Measurement Science (RSMS) Development project consists of state-of-the-art tools (vehicle, software, and hardware) necessary for making measurements to characterize spectrum occupancy, ensure equipment compliance, determine electromagnetic compatibility, and analyze interference problems. The development of the 4th generation system originated out of the recognized need to upgrade to the latest technology used in RSMS operations. RSMS operations, in turn, directly supports NTIA by providing critical measurement support for determining policies affecting both the public and private sectors. To this end, several new capabilities and improvements have been added to the system in FY 2005.

Integral to the RSMS measurement system has been the development of customized preselector units that filter out unwanted signals and amplify the input to increase system sensitivity. Recently, two new fully functional 4th generation preselectors have been designed and constructed — one for frequencies between 0.5 – 18.0 GHz and the other for frequencies between 18.0 – 26.5 GHz. Both preselectors are protected against strong signals by highly shielded enclosures and are controlled via fiberoptic connections to prevent signals coupling into control lines. In addition to these 4th generation units, several preselectors have been custom-designed specifically for Land Mobile Radio (LMR) measurements. Because the RSMS system has several functional preselectors from previous generations, each of these existing units has also been refurbished and improved upon so as to maintain a large selection of usable devices. Under the development of the 4th generation software, computer automated control of each of the units — new and old — has been integrated into the larger software package. Modularized instrument software units have made it possible to seamlessly swap out preselector units for different applications of the same measurement capabilities.

Currently in progress is the development of real-time "signal direction finding" capabilities. Two student interns, along with ITS engineering staff, have been working together to develop these capabilities through implementation of digital control and processing using Field Programmable Gate Array (FPGA) technology. The system switches through the different antennas of a six-sided array to determine the angle of signal arrival. Using rapid digital processing and a switch control by the FPGA, information is relayed via the Internet to a computer, which can then be used for real-time high-gain antenna positioning toward stationary or moving targets. One of the advantages of this system over most off-the-shelf systems is that it can be used with pulsed signals such as radar. By implementing this system in software as an instrument module, it is easily integrated into the larger RSMS software package for use with a variety of measurement capabilities. Development of this system using FPGA technology will not only provide signal direction finding capabilities but opens up a whole new way of acquiring and processing data using what is essentially a hardware re-programmable instrument that can be used for many different applications.

Recently implemented and used in Washington, DC, and Denver, a fully automated LMR channel occupancy measurement system has been developed by ITS. Using the latest in digital signal processing capabilities, this system simultaneously acquires data on as many as 480 LMR channels, performs processing to remove artifacts, and stores data every second. This new system is an improvement over previous systems in that it can acquire data much more rapidly, and it has enhanced capabilities for removing artifacts such as noise, a wide dynamic



Interior of RSMS 4th generation truck showing setup for LMR measurements taken in the Denver area (photograph by J.R. Hoffman).

range, and because of special processing techniques, a better sensitivity. In addition to the acquisition software, a whole suite of data processing routines have been developed that allow us to look at statistics in ways we have never been able to do before. Because of the versatile nature of the system and the development of a complete set of automated processing routines, application of this system for further measurements in other locations is highly possible and could be implemented efficiently.

Three newly developed additions to the RSMS software include: (1) a rotator instrument control, (2) an azimuth signal search routine, and (3) an enhanced stepped frequency measurement. The rotator instrument control is a software module integrated into the larger RSMS software that allows remote control of an antenna position device. This module can, in turn, be used in combination with a spectrum analyzer control routine for measurements such as the azimuth signal search routine which locates the direction of one or more signal point sources as it sweeps the horizon. The stepped frequency routine is a measurement procedure, used typically for radar measurements, in which the system steps through a narrow bandwidth of frequencies and measures the power. This allows the measurement of signals with a very large dynamic range of power. The FY 2005 enhancement to this routine comprised adding an automated attenuation capability which further increased the capability for measuring wide dynamic ranges.

New features planned for FY 2006 include enhanced data file management, a fully automated swept measurement routine, a swept calibration routine, a yttrium-iron-garnet (YIG) filter calibration routine, a vector signal analyzer instrument control module, two new noise measurement routines, and a scheduler for automated control of multiple measurements.

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Table Mountain Research Program

Outputs

- Measurements of aggregate emissions from dynamic frequency selection (DFS) RLAN-type transmitters.
- A prototype of a 3-axis antenna built to study the total incident field and polarization of radiated signals.
- Signal simulators developed to study the characteristics of complex signals such as UWB and man-made noise.

The Table Mountain Field Site and Radio Quiet Zone supports fundamental research into the nature, interaction, and evaluation of telecommunication devices, systems, and services. To achieve this goal, the Table Mountain Research Project actively solicits research proposals both from inside the Institute and from external agencies.

The results of this work are disseminated to the public via technical reports, journal articles, conference papers, web documents, and computer programs. Some highlights of the program are presented below.

Radar Testing

It was suggested by the International Telecommunication Union - Radiocommunication Sector (ITU-R) Working Party 8B that radar emission spectra might vary as a function of the pointing angle of radar antennas as they turn. If true, it would not be possible to determine a radar's emission spectra by simply measuring at a single location. To assess the possibility that this effect might occur, a maritime radar was set up at the Table Mountain site and its spectrum measured at four different azimuthal locations (see Figure 1). The results, documented in NTIA Technical Memorandum TM-05-430, indicated that no such effect is likely to occur.

Other experiments explored the possibility of antenna pattern variations that occur as a function of frequency.

DFS Testing

In other work, dynamic frequency selection (DFS) radio local area network (RLAN)-type device prototypes operating at 5 GHz were tested at Table Mountain as aggregates of up to ten clients communicating with an access point (see Figure 2). The purpose of the tests was to determine the spectrum and amplitude probability distribution (APD) characteristics of aggregate DFS emissions. The results of the work were forwarded to the NTIA Office of Spectrum Management (OSM), as part of a broader study of the performance and effectiveness of the DFS prototypes.

Land Mobile Radio Occupancy Measurements

In the fall of 2004, measurements were conducted in the Washington, DC, area to measure Land Mobile Radio (LMR) channel occupancy in Federal bands 162-174 MHz and 406-420 MHz. This was part of the NTIA effort to improve the spectrum efficiency of Federal radio usage. The goal was to obtain data needed to design shared communication systems for Federal users, and to determine long-term usage trends by comparing results with previous measurements taken in the same location in 1986 and 1989 (see pp. 6-7 for more information).

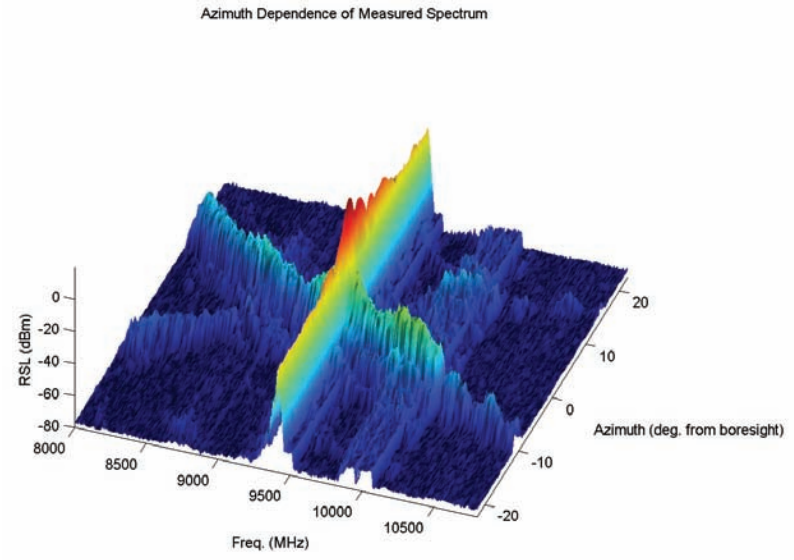

Figure 1. Three-dimensional view of radar azimuthal emission patterns from 8000-10800 MHz, between ±20 degrees of the radar main beam direction. The color is keyed to received signal level (RSL).

Figure 2. DFS testing at Table Mountain (photograph by F.H. Sanders).

During the summer of 2005 the Table Mountain Research project provided the resources needed to improve upon the existing LMR measurement system. This time the system was deployed to the Denver metropolitan area, and in addition to the frequency bands measured in Washington, DC, preparations were made to measure in bands 30-50 MHz, 138-162 MHz, and 420-450 MHz, as well as several bands in the 800 and 900 MHz regions of the spectrum. The Denver measurements will serve two purposes: (1) to check out recent changes to the measurement system and (2) to supplement the Washington, DC, measurements by measuring LMR usage of both Federal and non-Federal bands in a large city where transmissions are less centrally located.

FY 2005 Cooperative Research Programs
(see pp. 50-51 for more information)

- First RF Corporation
- RF Metrics Corporation
- Coherent Technologies
- Deep Space Exploration Society
- University of Colorado

Recent Publications

F. Sanders and B. Ramsey, "Phased array antenna pattern variation with frequency and implications for radar spectrum measurements," NTIA Report TR-06-436, Dec. 2005.

F. Sanders and B. Ramsey, "Comparison of radar spectra on varying azimuths relative to the base of the antenna rotary joint," NTIA Technical Memorandum TM-05-430, Aug. 2005.

T. Brown, S. Doshi, S. Jdhav, D. Henkel, and R. Thekkekunnel, "A full scale wireless ad hoc network test bed," in "Proceedings of the International Symposium on Advanced Radio Technologies: March 1–3, 2005," J.W. Allen and J. Ratzloff (Eds.), NTIA Special Publication SP-05-418, Mar. 2005, pp. 51-60.

J.W. Allen, "Gain characterization of the RF measurement path," NTIA Report TR-04-410, Feb. 2004.

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Spectrum Efficiency Research and Engineering

Outputs

- Report on Federal LMR systems in Washington, DC, area.
- Internal papers on spectrum efficiency concepts.
- Consultation with OSM on spectrum efficiency planning.

NTIA is deeply committed to an extensive multi-pronged program to improve the spectrum efficiency of Federal radio systems. This program was given additional importance by the May 2003 announcement of a November 30 Presidential Spectrum Policy Initiative to promote the development and implementation of a U.S. spectrum management policy for the 21st century. More recently, NTIA administrator Michael Gallagher announced a multi-year effort to carry out a series of spectrum efficiency directives contained in a November 2004 Presidential Memorandum to multiple Federal departments. Although most of this work will be accomplished by NTIA/OSM in Washington, ITS is also playing a key role in several aspects of the work.

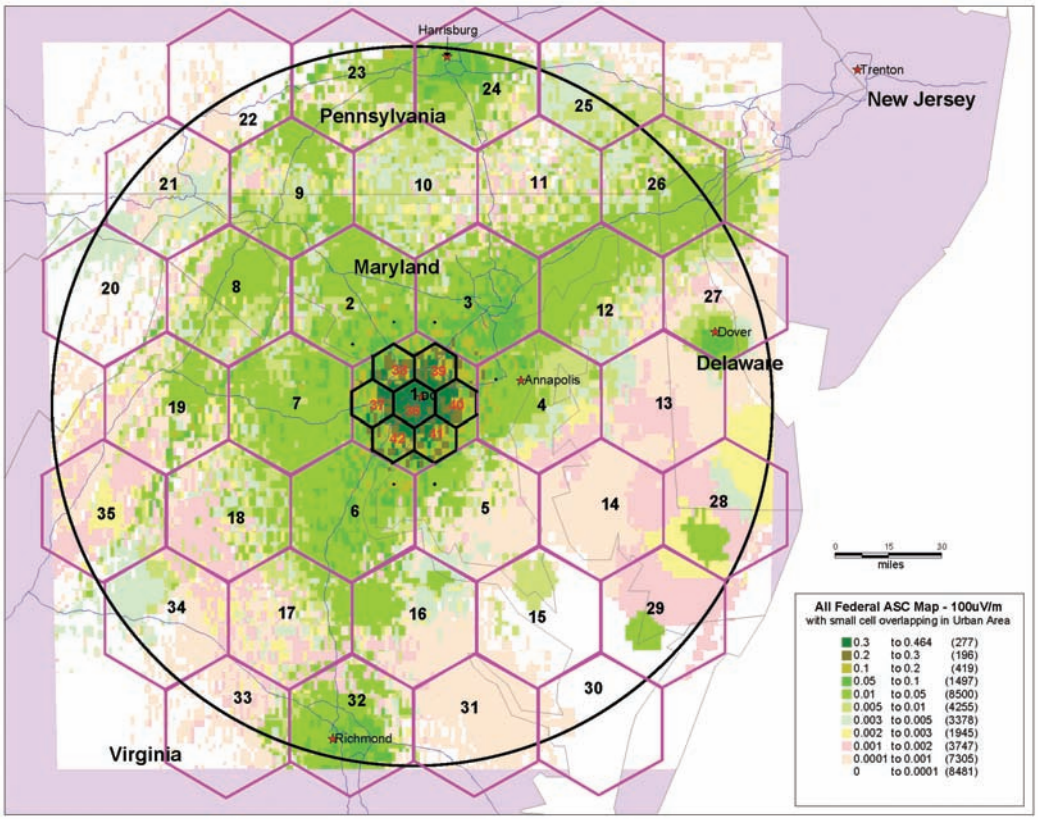
ITS is working with OSM to develop theoretical concepts and practical applications of improved spectrum efficiency. One problem is that "spectrum efficiency" can mean many things — some of them contradictory — and ITS has been active in helping to sort out concepts that will be useful in guiding Federal policies toward more effective use of the radio spectrum. An internal NTIA paper on spectrum efficiency concepts was written to guide discussion on some of the problematic aspects of spectrum efficiency that needed to be resolved to help NTIA develop improved policies and practices.

ITS is currently examining possible categories of definitions (sometimes equations) that describe the spectrum efficiency and effectiveness of several types of radio services. Initial work suggests that there is considerable flexibility in the choice of definitions; the choice will need to match the specific purposes for which the calculations will be performed. These definitions typically differ in the factors selected to represent significant features of the real world. Sometimes it is sufficient to consider only the technical characteristics of the radio equipment; sometimes it is necessary to consider how the equipment characteristics match the operational requirements of the mission. The computation methodologies and the numeric answers for a specific situation can differ considerably, depending on the nature of the definition that is selected.

ITS has been assisting OSM in a modeling effort to see whether the current myriad of single-agency Federal mobile radio systems in the Washington, DC, area could be efficiently replaced by one large shared trunked radio system. The first part of this work was completed in FY 2004, including a draft report "Phase 1 - Study of Federal operations in the 162-174 MHz band in the Washington, DC, area," which is now awaiting final clearance for publication. This work investigated the current Federal land mobile radio (LMR) systems within 100 miles of Washington, DC. This study developed a signal capacity (SC) model that uses Government Master File (GMF) Federal radio license data and terrain-based propagation models to provide a combined geographical coverage "footprint" of the multiple independent existing radio systems now serving Federal Agencies. This model showed that as many as 268 separate LMR radio channels were available to a mobile user in the downtown Washington area in the 162-174 MHz band, as well as summarizing the geographical coverage of current systems.

Another input to a model for the design of future LMR systems was the measurement of actual LMR traffic (Erlangs) in the Washington area, using the ITS Radio Spectrum Measurement Science (RSMS) system, as described on pp. 6-9 of this report. These measurements were completed in early 2005, and the results have been used to describe the total amount of traffic that a possible future shared radio system should be designed to handle. A report on the RSMS measurements should be published soon.

The design of possible future alternative shared LMR systems will be based on the signal capacity geographical coverage data and the RSMS measured traffic data. The figure shows the Average Signal Capacity (ASC) map for Washington, DC, overlaid with a 100-mi radius circle, and idealized hexagonal coverage areas for one of the proposed future



Possible future alternative shared LMR system using large cells overlapped with small urban cells.

systems. The ASC map shows the number of independent radio systems per square mile (actual ASC values are multiplied by 10,000 on the map). This ASC data is summed over the coverage area and multiplied by measured channel occupancy data to get the nominal traffic load in Erlangs that each cell must support. This example uses rural/suburban cells with a 20-mile coverage radius (violet hexagons) overlaid with 7-mile radius cells in the densest urban areas (small black hexagons). Several different architectures have been evaluated using various assumptions about the total number of users participating in the shared system, including traffic loads as large as ten times more than current traffic loads. A report on the completed evaluation will compare the expected costs and number of frequencies needed for the alternative future systems and the current LMR systems.

Recent Publications

J.R. Hoffman and R.J. Matheson, "RSMS measurement and analysis of LMR channel usage," in "Proceedings of the 2005 International Symposium on Advanced Radio Technologies: March 1-3, 2005," J.W. Allen and J. Ratzloff (Eds.), NTIA Special Publication SP-05-418, Mar. 2005.

R.J. Matheson, "Flexible-use spectrum rights". in "Proceedings of the 2005 International Symposium on Advanced Radio Technologies: March 1-3, 2005," J.W. Allen and J. Ratzloff (Eds.), NTIA Special Publication SP-05-418, Mar. 2005.

G. Patrick, et al., "Phase 1: Study of Federal operations in the 162-174 MHz band in the Washington, DC, area," NTIA Report in progress.

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Signal Characteristics, Spectral Emissions, and Interference Analyses

Outputs

- Technical publications and presentations demonstrating research results.
- Comparative measurements and analyses of DP-UWB, DS-UWB, and MB-OFDM signals.
- Measurement and analysis of DTV susceptibility to ultrawideband signals.

Since the Federal Communications Commission (FCC) permitted low power ultrawideband (UWB) emissions between 3.1 and 10.6 GHz in February 2003, a number of companies have developed new UWB technologies for application in wireless personal area networking (WPAN) to achieve high data rates at short distances (nominally less than 10 meters). Examples of these developments include Multi-band Orthogonal Frequency-Division Multiplexing (MB-OFDM) and Direct-Sequence Ultrawideband (DS-UWB) technologies. MB-OFDM achieves its ultra-wide bandwidth with a 528-MHz wide OFDM signal that hops between 14 different bands. In contrast, DS-UWB combines conventional spread spectrum techniques and pulse shaping to achieve its ultra-wide bandwidth.

Questions arose regarding how UWB signals interfere with legacy systems such as C-band satellite television, which demodulates signals that lie within the frequency band allocated for UWB operations. On March 22, 2004, ITS entered into a Cooperative Research and Development Agreement with Motorola/Freescale Incorporated to address these questions. We hypothesized that UWB interference potential could be quantified in terms of UWB signal characteristics. To test this hypothesis, a test system was designed and built to inject UWB signals with known characteristics into a C-band satellite digital television (DTV) receiver and quantitatively measure interference susceptibility via signal quality metrics, e.g., segment error rate, pre-Viterbi bit error rate, and modulation error ratio, taken from various points in the receiver signal processing chain. Figure 1 shows the test set-up. Results from the experiment are being published in a three-part NTIA Report Series entitled “Interference Potential of Ultrawideband Signals.” Part 1, released in February 2005, describes the test setup and procedures in detail.

Figure 1. Test set-up (photograph by F.H. Sanders).

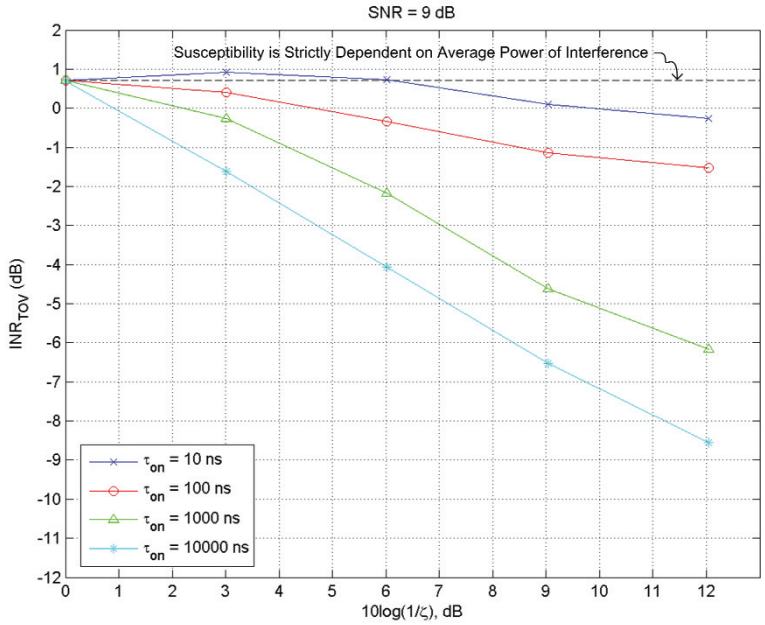

Figure 2. INR_{TOV} *versus 10log(1/ζ) for a DTV receiver operating at* SNR = *9 dB and exposed to gated noise interference.*

Part 2, released in August 2005, provides test results for gated-noise interference to DTV receivers. While continuous- and gated-noise signals are unlikely to be used in communications, their similarities to DS-UWB and MB-OFDM, respectively, are unmistakable and their analytic tractability is profoundly useful. This report demonstrates that DTV susceptibility to gated-noise interference cannot be predicted by interference power characteristics alone. As illustrated in Figure 2, it was found that DTV susceptibility, quantified by the average interference power that caused DTV degradation at the threshold of visibility (INR_{TOV}), is also dependent on temporal characteristics (e.g., τ_{on} and ζ) of the interfering signal and the bandwidth of the DTV receiver. Moreover, high correlation was observed between susceptibility and forward error correction performance of the receiver.

Part 3, *to be released*, will provide results from tests that measured DTV susceptibility to actual UWB signals. In this experiment, a DTV victim receiver was exposed to Dither-Pulse UWB, DS-UWB, and MB-OFDM interference. It was found that categorization of the UWB signals into three regions of common DTV susceptibility could be achieved with a priori knowledge of the temporal structure of the signal and bandwidth of the victim receiver.

Recent Publications

M. Cotton, R. Achatz, J. Wepman, and B. Bedford, "Interference potential of ultrawideband signals, Part 1: Procedures to characterize ultra-wideband emissions and measure interference susceptibility of C-band satellite digital television receivers," NTIA Report TR-05-419, Feb. 2005.

M. Cotton, R. Achatz, J. Wepman, and P. Runkle, "Interference potential of ultrawideband signals, Part 2: Measurement of gated-noise interference to C-band satellite digital television receivers," NTIA Report TR-05-429, Aug. 2005.

M. Cotton, R. Achatz, J. Wepman, and R. Dalke, "Interference potential of ultrawideband signals, Part 3: Measurement of ultrawideband interference to C-band satellite digital television receivers," NTIA Report in progress.

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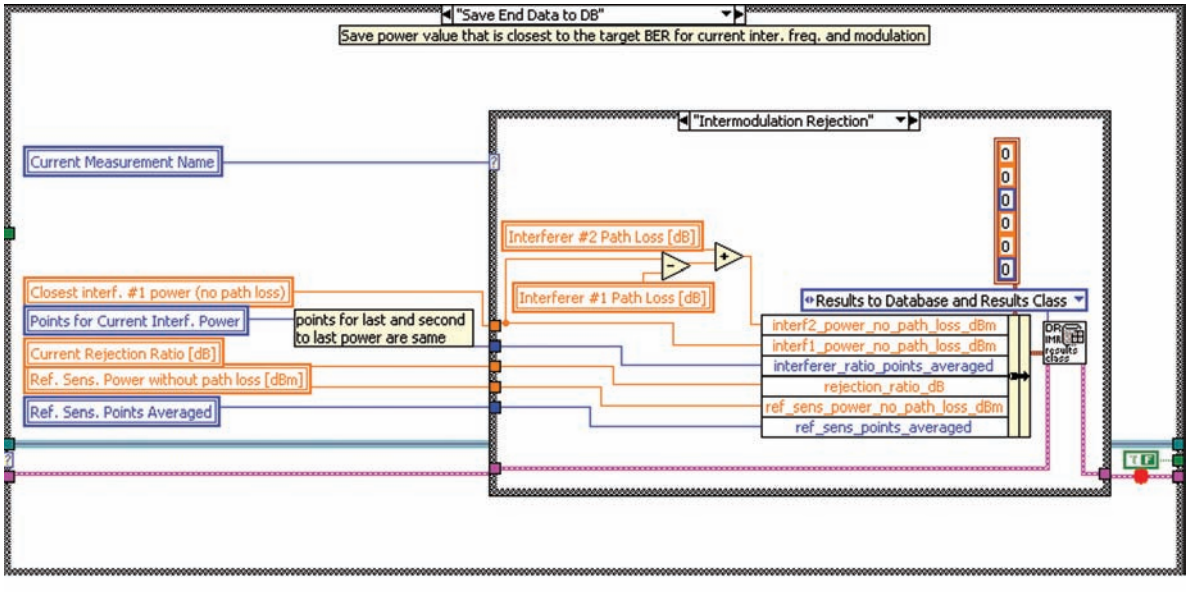


Test and Evaluation is an integral element of ITS' Public Safety Telecommunications Interoperability efforts. The Institute is developing an automated suite of performance measurements that will be the basis for a national Project 25 Compliance Assessment Program (photograph by F.H. Sanders).

Telecommunications and Information Technology Planning

The telecommunications and information technology planning function represents the highest-level system or network perspective of the Institute. This work can be characterized generally as planning and analyzing existing, new, and proposed telecommunications and information technology systems, especially networks, for the purpose of improving efficiency and enhancing the technical performance and reliability of those systems. In many cases, ITS performs this work for both wireline and wireless applications. This portion of the ITS technical program encompasses work that is frequently referred to in industry as "systems engineering."

All phases of strategic and tactical planning are conducted under this work area; problem solving and actual implementation engineering also are done. ITS engineers identify or derive users' functional requirements and translate them into technical specifications. Telecommunication system designs, network services, and access technologies are analyzed, as well as information technologies (including Internet and Internet-related schemes). Associated issues, such as network management and control and network protection and privacy, also are addressed. Integration of individual services and technologies is a common task in many projects, along with the application of new and emerging technologies to existing applications.

Following is a summary of significant activities that occurred in the area of telecommunications and information technology planning during FY 2005. By far, telecommunications interoperability was the largest program area.

Areas of Emphasis

Interoperability Efforts for Justice/Public Safety/Homeland Security
The Institute conducts a broad-based technical program aimed at facilitating effective telecommunications interoperability and information-sharing among dissimilar wireless and information technology systems within the justice/public safety/homeland security community. ITS activities are sponsored by a number of Federal agencies and programs, and are planned and performed only after close coordination with local, State, tribal, and Federal practitioners. Technical thrusts within the program, which are described in separate sections on the following pages, include:

Engineering Support and Coordination

Information Technology Interoperability Standardization and Quality

Wireless Telecommunications Interoperability Standardization

Emergency Telecommunications Service (ETS)
The Institute develops and verifies ETS Recommendations for International Telecommunication Union - Telecommunication Sector (ITU-T) Study Group 9. A second project provides ETS expertise relating to ANSI-accredited Performance, Reliability, and Quality of Service Committee, PRQC (formerly T1A1). These projects are funded by the National Communications System (NCS).

Engineering Support and Coordination for Justice/Public Safety/Homeland Security

Outputs

- Interoperability and performance evaluations of Project 25 equipment.
- Automated suite of Project 25 Radio Performance Measurements.

ITS is conducting a technical program aimed at facilitating effective interoperability and information sharing among dissimilar wireless telecommunications and information systems within the justice/public safety/homeland security community. The primary focal points of the program are: (1) Standards support, (2) Test and Evaluation (T&E), (3) Research and Development (R&D) support, and (4) Technical Coordination among local, State, tribal, and Federal departments and programs associated with interoperability activities. All efforts described here are complementary to the ITS technical programs focused on wireless telecommunications interoperability standardization and information technology interoperability standardization. The ITS program is sponsored by a number of different Federal departments and programs that have a keen interest in public safety interoperability, including: National Institute of Standards and Technology (NIST) Office of Law Enforcement Standards (OLES), Department of Justice Office of Community Oriented Policing Services (COPS), Department of Homeland Security's (DHS) Public Safety Wireless Communications (SAFECOM) Program, and the Federal Partnership for Interoperability Communications (FPIC).

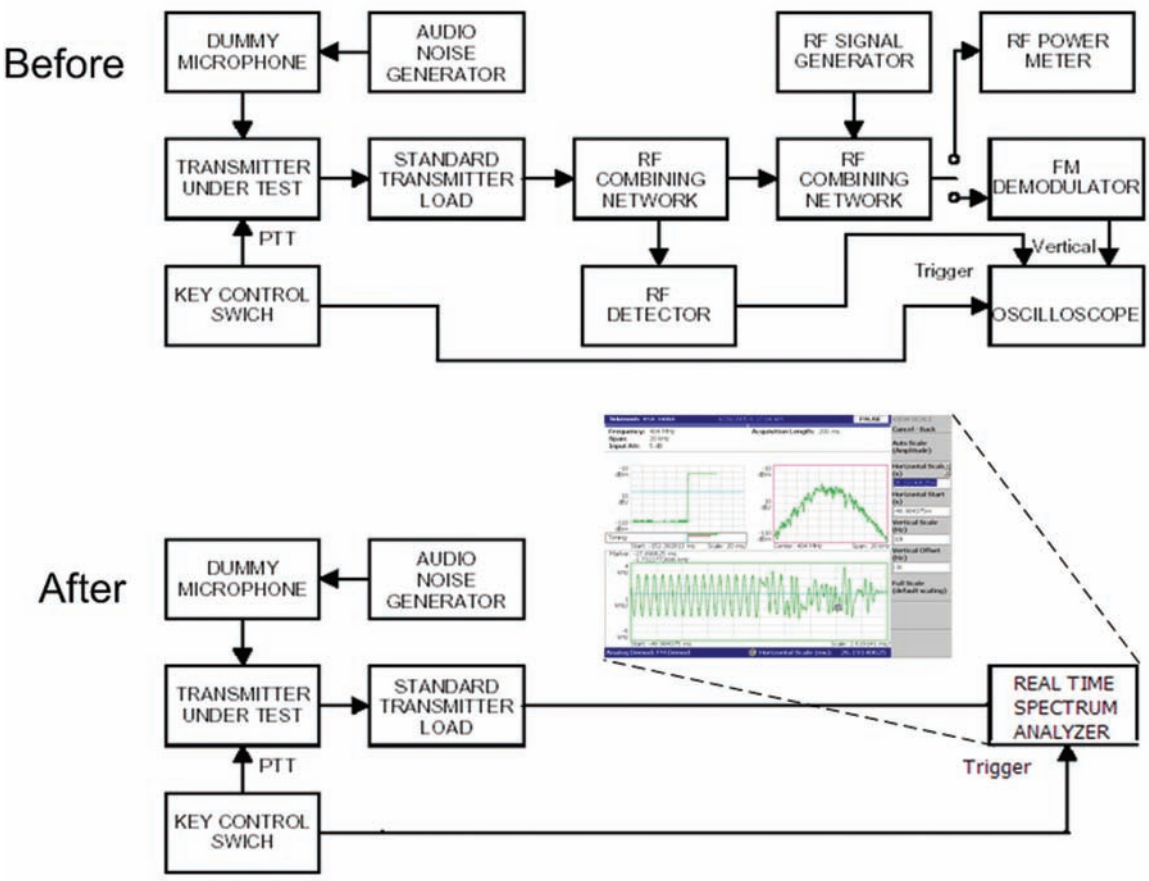
Standards Support

Through research conducted in its Interoperability Research Laboratory (IRL), ITS has made significant contributions to standards development organizations supporting justice, public safety, and homeland security goals. Following up on last year's performance and interoperability tests which demonstrated multiple failures among a considerable sample of Project 25 (P25) subscriber units, the Project 25 Steering Committee in April 2005 formally requested that NIST/OLES work in conjunction with ITS to establish a P25 Compliance Assessment Program. Accordingly, ITS engineers have taken a lead role in describing the framework and defining the critical elements of such a program and are presently assisting the Steering Committee and appropriate Telecommunications Industry Association (TIA) TR-8 subcommittees in the establishment of the program and the development of the functional test procedures which underpin it. These test procedures include evaluations of performance, interoperability, and conformance for each system interface. This year ITS focused on evaluating and proofing the performance measurement procedures defined in TIA-102.CAAA and has recommended dozens of editorial comments and procedural enhancements for that document. For example, as shown in the figure, an instrument with multi-domain views can replace six separate test devices, greatly simplifying the test procedures. In addition, ITS engineers are actively involved in completing and publishing an interoperability test procedure for P25 trunked radio systems. In the coming year, work on encryption tests and common air interface conformance tests will commence.

In addition, ITS engineers made considerable progress toward developing and documenting a repeatable Delivered Audio Quality (DAQ) test measurement. An automated test routine was developed and the functionality of the program proven. Test subjects containing recently standardized enhanced vocoders are expected next year. The DAQ definition project will provide clear and concise instructions on how to perform objective audio quality measurements. The published results will be backed by a publicly available, exhaustive compendium of thousands of audio recordings of impaired RF channels which will enable third parties to investigate possible means of automating such measurements.

Test and Evaluation

The IRL has been equipped to support a broad variety of testing requirements, especially public safety applications. Demonstration type testing continued this year with greater attention being paid to the measurement methods and procedures for testing the electrical performance of P25 radios. ITS engineers reviewed the suite of tests identified in the TIA-102.CAAA test document and selected a number of viable procedures which would provide a useful characterization of the performance of various subscriber units. Ultimately 18 receiver and transmitter



Test procedure for P25 subscriber units. An instrument with multi-domain views can replace six separate test devices, greatly simplifying the test procedure.

test procedures were selected, mocked-up, and documented.

R&D Support

At the request of several Federal Departments and Programs, ITS worked alongside practitioners from the justice/public safety/homeland security community to technically evaluate grant proposals. By acting as the Government's common "technical thread," ITS engineers helped ensure that R&D proposals from industry and telecommunications integration proposals from local, State, and tribal government agencies were feasible and consistent with long-term interoperability strategies. Evaluations were conducted on behalf of SAFECOM's Request for Information on Rapidly Deployable Interoperability Solutions, the COPS Program, and DHS's Emergency Preparedness and Response Directorate.

On behalf of NIST/OLES, in support of the Project 25 Compliance Assessment Program, ITS engineers have embarked on a program to develop and deploy an automated suite of performance measurements to test P25 subscriber units. The software suite which automates 18 typical receiver and transmitter measurements will be made available to manufacturers and third-party independent laboratories involved in the compliance assessment process.

Other Support

In addition to the established areas of activity mentioned above, ITS frequently responds to the immediate needs of its sponsors by performing a variety of other research and applied engineering activities. These activities may include strategic and tactical planning, system engineering, technical analysis, and economic benefit studies.

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Information Technology Interoperability Standardization and Quality for Justice/Public Safety/Homeland Security

Outputs

- XML Data Model and Data Dictionary.
- Audio quality testing.

ITS is conducting a technical program aimed at facilitating effective interoperability and information sharing among dissimilar information systems within the justice/public safety/homeland security community, and ensuring that there are standardized procedures to measure the quality of speech delivered through public safety's communications systems.

The primary focal points of the information technology (IT) interoperability portion of the program are: (1) the identification and delineation of applicable information sharing architectures, (2) coordination between major Federal players and local and state public safety practitioners to collegially develop a nationwide strategic plan for information sharing, and (3) the identification and/or development of standards that address the community's requirements and are in conjunction with the strategic plan. All efforts are aimed at allowing local, State, and Federal agencies to exchange information, without requiring substantial changes to internal systems or procedures.

The focal point of the audio quality portion of the program is to provide a facility that can emulate, in a controlled laboratory environment, the field conditions experienced by public safety practitioners.

The ITS program is sponsored by a number of different Federal departments and programs that have a keen interest in public safety interoperability, including: National Institute of Standards and Technology (NIST) Office of Law Enforcement Standards (OLES), Department of Homeland Security's Public Safety Wireless Communications (SAFECOM) Program, Department of Homeland Security Chief Information Officer's Wireless Management Office (WMO), Department of Justice Office of Community Oriented Policing Service (COPS), National Institute of Justice (NIJ) CommTech Program (formerly AGILE Program), and NTIA.

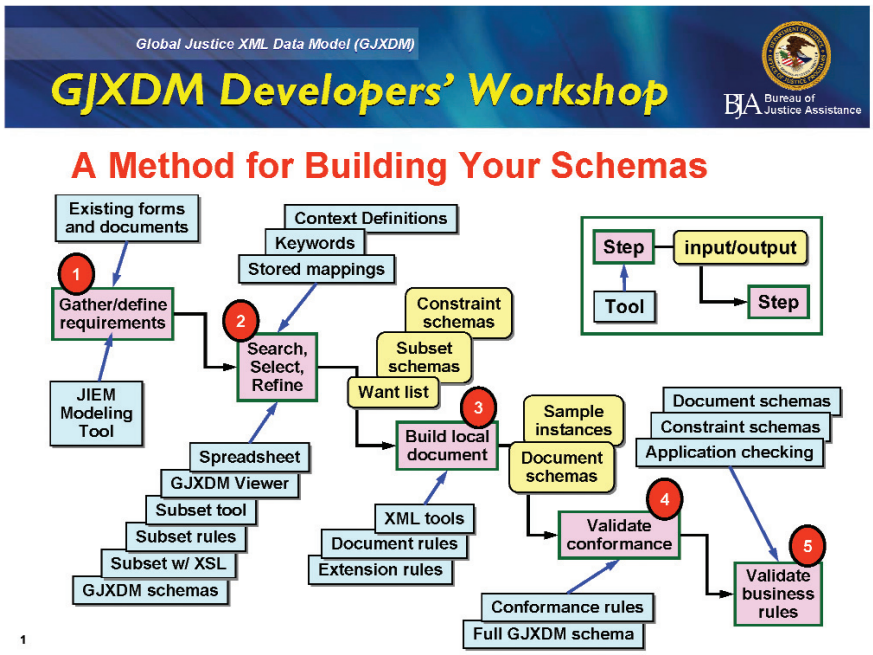

Figure 1. Structured process for GJXDM Exchange Document Development.

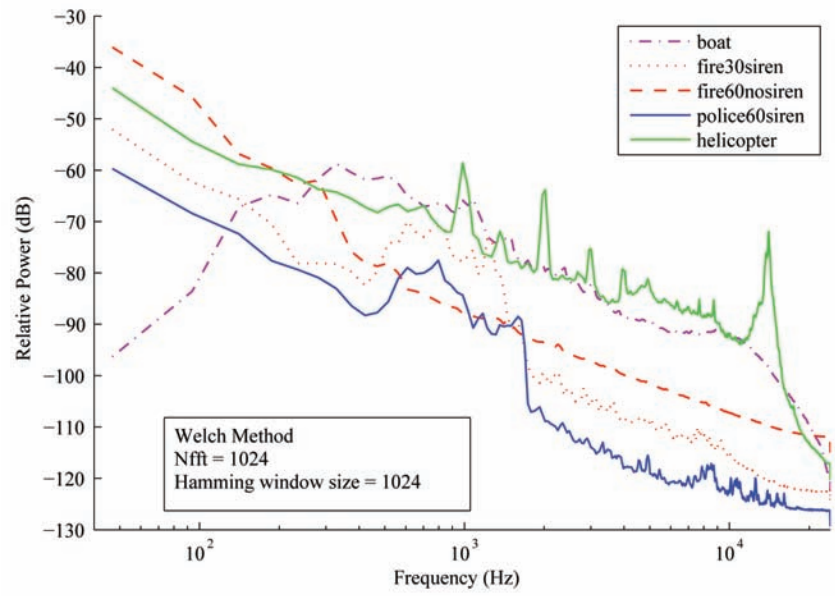

Figure 2. Noise spectra of public safety operating environments.

XML Data Model and Data Element Dictionary Development

In prior years, ITS played a significant role in providing technical assistance and coordination in the initial development of an Extensible Markup Language (XML) Data Element Dictionary that can provide common "words" for a common "language" to be used by the justice/public safety/homeland security community. The public release of the Global Justice XML Data Model (GJXDM), the data dictionary along with an associated data model, was in 2004.

While the release of the GJXDM was a significant step forward in achieving information sharing interoperability among members of the justice and public safety community, it is a very complex model. Thus, FY 2005 efforts primarily focused on training and education related to the data model. This includes guidance for structured development of documents to be exchanged, and messages to be passed, shown in Figure 1 on the previous page. Users and developers use the "words" of the Data Dictionary to build documents that represent a particular information exchange. The current released version of the GJXDM is available to the public at http://it.ojp.gov/gjxdm/.

The next phase of development for the XML data model was identified in 2005: the National Information Exchange Model (NIEM). The NIEM uses the foundation of the GJXDM to extend the architecture of the data model to the broader context of Justice and Homeland Security. The first public version of the NIEM is expected in 2006.

Audio Quality Testing for Public Safety

There are several reasons for developing high-quality acoustic coupling capabilities to provide speech stimulus to public safety communications devices. One is that the electrical interfaces are non-standard and highly specific to each manufacturer and/or device model. Another is that acoustic coupling provides a means to perform calibrated laboratory emulation of the acoustic environment experienced in the field.

One of the most severe challenges that public safety practitioners face is the extreme nature of the environment in which they must operate. Of particular impact to speech quality is the variety and volume of noise environments. Public safety equipment operates at high noise levels with disparate noise spectra even before the inclusion of application specific features such as sirens (see Figure 2 above). These make for very challenging communication scenarios.

The first subjective test to evaluate public safety practitioner opinion of quality in the presence of real public safety background noise was conducted in 2005. The test was specifically requested by the Project 25 Steering Committee for the purpose of evaluating enhancements in vocoder technology since the initial adoption of a Project 25 standard vocoder in 1998. The test results showed that there had been significant improvements in quality that would not impact interoperability, and based on that information, the Project 25 Steering Committee immediately moved to adopt the newer, higher-quality, version of the vocoder.

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Wireless Telecommunications Interoperability Standardization for Justice/Public Safety/Homeland Security

Outputs

- Wireless telecommunications Statement of Requirements (SOR) for Public Safety.
- Functional and performance specifications for Project 25/TIA digital radio & system standards.
- Standardized measurement methods for testing Project 25 radios and systems.

Too often, public safety practitioners' communications systems do not meet their needs for *operability* (security, service area, performance, and survivability for intra-agency communications) and *interoperability* (inter-discipline and inter-jurisdiction communications where and when communications are needed). The public safety community recognizes that five steps are needed to specify and implement wireless systems: (1) define *user requirements* for communications and information exchange, (2) specify the *architecture framework* to support the communications, (3) develop *standards* for the systems, (4) conduct *technology performance tests* to evaluate proposed solutions for the standards, and (5) conduct *vendor products functional tests* to validate that tested equipment supports the standards prior to implementation. ITS is the common technical thread through all these steps and it conducting a technical program aimed at facilitating effective interoperability and information sharing among dissimilar wireless telecommunications systems in the justice/public safety/homeland security community.

The ITS program is sponsored by several Federal departments and programs with a keen interest in public safety interoperability, including: National Institute of Standards and Technology (NIST) Office of Law Enforcement Standards (OLES), Department of Justice Office of Community Oriented Policing Services (COPS), Department of Homeland Security's Public Safety Wireless Communications (SAFECOM) Program, Federal Partnership for Interoperable Communications (FPIC), and the Department of Homeland Security Chief Information Officer's Wireless Management Office (WMO).

Wireless Telecommunications Statement of Requirements (SOR)

Public safety communications are often too critical and unique to rely on traditional solutions. To have a vision of their communications and information sharing needs, the public safety practitioners have defined their functional and operational tasks while relating their communications needs now and into the future. ITS has helped document that vision in *Statement of Requirements for Public Safety Wireless Communications and Interoperability – Version 1.0*, at http://www.safecomprogram.gov/SAFECOM/library/technology/1200_statementof.htm. This SOR is focused on the functional needs of public safety first responders — Emergency Medical Services (EMS) personnel, fire fighters, and law enforcement officers — to communicate and share information as authorized when it is needed, where it is needed, and in a mode or form that allows the practitioners to use it effectively. The communications mode may be voice, data, image, video, or multimedia that includes multiple forms of information. To keep the emphasis on functional requirements, the SOR avoids specifying either technologies or business models (i.e., whether requirements should be addressed through owned products and systems, or via commercial services). With aid of ITS, the practitioners will soon have available Versions 1.1 and 2.0 that will provide more detail on technical parameters and values derived from subjective practitioner tests designed to evaluate quality and performance requirements of the communication systems and services.

Wireless Communications and Information Exchange Architecture Framework

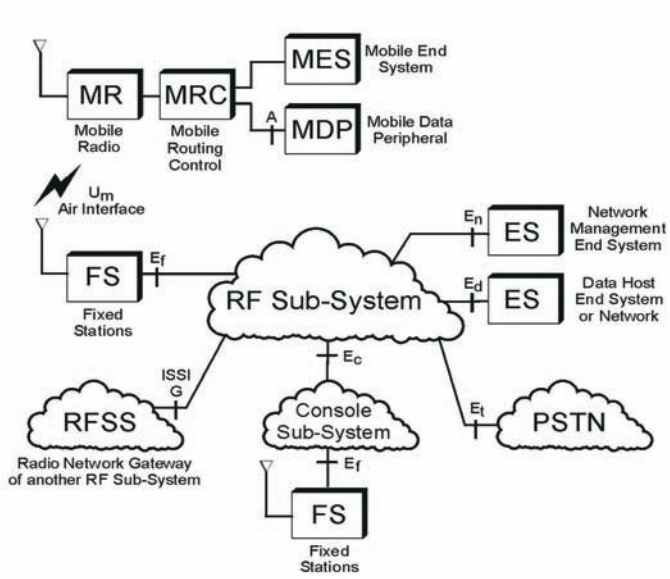
Through its sponsors, ITS is supporting the development of an architecture framework for wireless communications and information exchange interoperability. Working with SAFECOM and others, ITS is expediting the overall Federal effort by taking advantage of background engineering work already conducted. For example, ITS has investigated frameworks for high-level enterprise architectures, and is also reviewing and analyzing the wireless integration activities being performed, and contemplated, to characterize common architectural elements that

have been successfully applied in the field. Governance and other non-technical issues have also been researched. Once the architecture framework (system of systems) document matures, it will be reviewed and approved by practitioners as was the SOR. The framework will then guide the development of standards that support it.

Project 25/TIA TR-8 and Project MESA

Standards development activities for the public safety community's new generation digital land mobile radio systems are being performed under a joint effort of public safety users and equipment manufacturers. The users are represented by local, state, and Federal government organizations, and manufacturers are represented by industry members of the Telecommunications Industry Association (TIA). This standards development process is known as Project 25 (P25). P25 members establish user requirements and draft specifications based on the users' perspective, and TIA (and its TR-8 Committee) uses processes accredited by the American National Standards Institute to develop formal, nationally recognized standards that can be used to design and manufacture equipment and evaluate its performance and interoperability. ITS represents users on technical contributions and issues and provides guidance when technical decisions are to be made. ITS holds leadership positions within P25 Working Groups: Vice Chair of the ISSI Task Group and Vice Chair of the Project 25 Systems Architecture Working Group (PSAWG); and Chairman of the BroadBand Task Group (BBTG). In addition, an ITS engineer represents Federal users on the Project 25 Steering Committee.

With Congress providing grants to state and local governments for telecom equipment and the funding for Federal public safety communications systems, Congressional bills have defined the importance of having P25 standards in place. As a result, the P25 Steering Committee and technical committees have set aggressive timeframes for completion of the documents that make up the standards associated with each P25 interface. The interfaces defined with the highest priority for completion (shown in the figure) are the Inter-RF SubSystem Interface (G, ISSI), the Fixed Station SubSystem Interface (E_f, FSSI), and the Console SubSystem Interface (E_c, CSSI).



P25 system interfaces.

Standards for these interfaces will be in place in late 2006, and will be sufficient for manufacturers to begin building, testing, and delivering products. Commercially available equipment is expected to be available 12-18 months after the standards are approved. ITS continues to be active and instrumental in helping to accelerate the technical completion of these critical interfaces.

ITS continues to develop procedures to test the performance and interoperability of P25 radio systems. In FY 2006, the Conformance Test Procedure documents will be put into the P25 process for review and consensus acceptance.

For Project MESA, a joint effort of the European Telecommunications Standards Institute (ETSI) and TIA, efforts have concentrated on defining the public safety requirements for broadband mobile applications worldwide. ITS has provided user operational requirements that represent the views of U.S. public safety users. An ITS engineer is Chair of the Technical Specification Group — Systems.

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Emergency Telecommunications Service (ETS)

Outputs

- Technical contributions to ATIS Technical Committee PRQC.
- Technical contributions to ITU-T Study Group 9.

In the aftermath of the 2001 terrorist attacks, the Federal Government has become very interested in priority treatment for emergency communications. While the Government Emergency Telecommunications Service (GETS) has served emergency workers well for many years, it is limited to the Public Switched Telephone Network (PSTN) and to the United States. ETS is envisioned as a GETS-like service that will be available internationally and encompass virtually all wireless and wireline communications networks. The types of traffic to be carried include voice, video, database access, text messaging, e-mail, FTP, and web-based services.

The ETS effort at ITS encompasses two projects: Packet-Switched Networks, and Network Survivability and Restoral. For both of these projects, laboratory studies, security analyses, and standards development are used to support Critical Infrastructure Protection (CIP) initiatives. These two projects are funded by the National Communications System (NCS). This work supports NCS in its mission to protect the national security telecommunications infrastructure, and to ensure the responsiveness and availability of essential telecommunications during a crisis.

In the first project, Packet-Switched Networks, ITS develops and verifies ETS Recommendations for International Telecommunication Union's Telecommunication Standardization Sector (ITU-T) Study Group (SG) 9. The major goal of this project is to ensure that future ETS mechanisms and the current GETS service will interoperate over broadband cable television networks in the delivery of voice and multimedia communications.

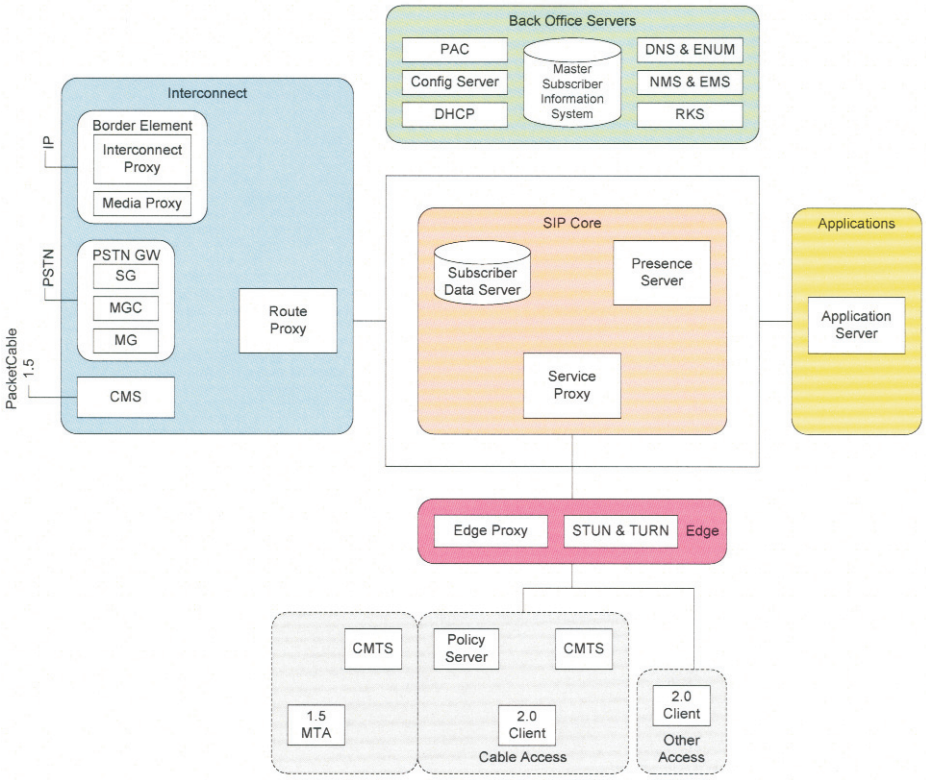

Figure 1. IPCablecom 2 reference architecture.

The second project, Network Survivability and Restoral, provides ETS expertise relating to priority support and network security for the American National Standards Institute (ANSI)-accredited Performance, Reliability, and Quality of Service Committee, PRQC. Within this project, an ITS engineer served as a co-editor of several ANSI and Alliance for Telecommunications Industry Solutions (ATIS) Standards and Technical Reports. These Standards and Technical Reports provide guidelines, specifications, and requirements for aspects of

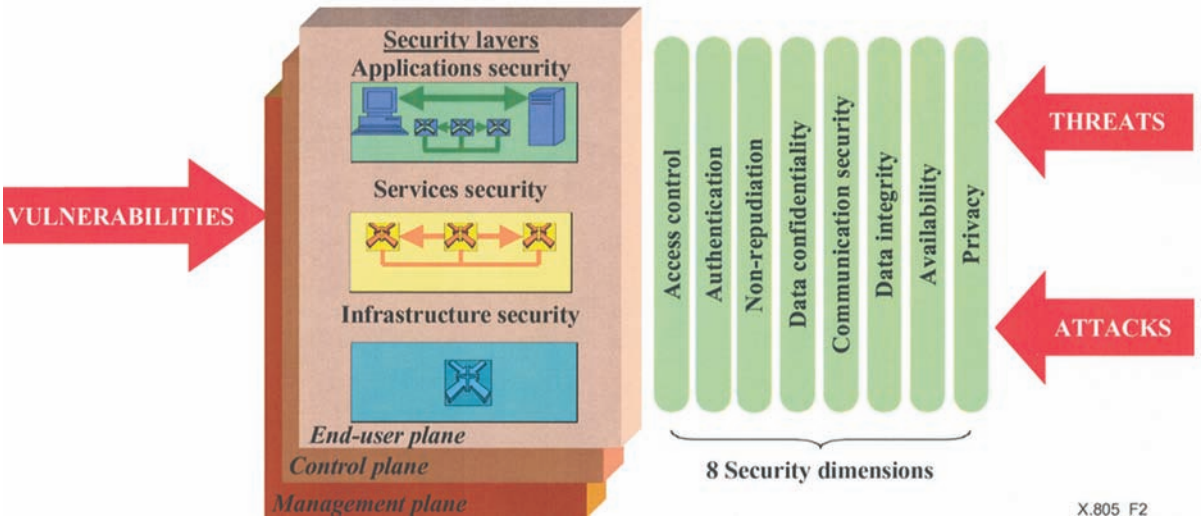

Figure 2. Security planes reflect the different types of network activities.

ETS communications. An ITS Engineer serves as the Chair of PRQC's Security Task Force where he leads security standardization for the Network User Plane.

The standardization work in ITU-T SG 9 is focused on the IPCablecom family of Recommendations. These Recommendations define the protocols and signaling to be used on broadband cable television networks to support telephony, multimedia, and Internet access. The IPCablecom Recommendations have been standardized in ITU-T SG 9, and equipment implementing them is currently in production worldwide. One of the goals of this project is to identify where additions or changes might be needed to support the ETS. This effort also involves work with the Internet Engineering Task Force (IETF), since many of the underlying protocols used in IPCablecom (as well as some of the ETS mechanisms) are under development in the IETF. An ITS engineer served as the Editor and principal author of ITU-T Recommendation J.260 — "Requirements for preferential telecommunications over IPCablecom networks" in SG 9. This Recommendation was approved in January of 2005. An ITS engineer also serves as the Editor of Draft new ITU-T Recommendation J.PREF — "Specifications for preferential telecommunications over IPCablecom networks" in SG 9. This Recommendation will provide specifications to satisfy the requirements set forth in J.260.

Another important study underway at ITS is a series of tests of GETS over IPCablecom networks. The evolution of GETS from a PSTN-only service to one that will interoperate over the wireless, IPCablecom, and Next Generation networks (NGN) is an NCS goal. Another goal of the ETS effort is determining the security needs of ETS in IPCablecom networks.

Figure 1 is a diagram of the IPCablecom2 Architecture. IPCablecom 2 will be the next generation of IPCablecom and we expect to include support for ETS in the first version of IPCablecom2. Figure 2 shows the X.805 diagram with different Security planes reflecting the different types of network activities. Joint effort with the other ATIS groups doing security work will allow us to better define and coordinate this important network security work.

In FY 2006, ITS will continue to address work on the development and standardization of ETS in ATIS PRQC, the IETF, and ITU-T SG 9. The projects will address technologies in the NGN and interactions with the IPCablecom networks. This work on ETS must of necessity be conducted with the help of representatives from network providers and cable television equipment manufacturers, as well as NCS. The work in FY 2006 will focus on priority and security in the NGN ETS as well as GETS compatibility in the IPCablecom networks.

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The NTIA/ITS booth at MILCOM (photograph by T.J. Riley).

Telecommunications Engineering, Analysis, and Modeling

The Telecommunications Engineering, Analysis, and Modeling Division conducts studies in three areas for wireless and wireless-wireline hybrid applications.

Engineering encompasses technical assessment of telecommunications systems, their components, and their performance, including impact of access, interoperability, timing and synchronization, and susceptibility to noise and interfering signals on system effectiveness in national security/emergency preparedness (NS/EP), military, and commercial operational environments.

Analysis is often performed in association with the Telecommunications Analysis (TA) Services project which offers analytical tools via an on-line cooperative research and development agreement (CRADA) over the Internet. ITS can also customize these tools and analyses for larger projects and specialized applications, for example, the geographic information system (GIS) tools project funded by the Department of Defense.

Modeling is one of ITS's core strengths. Propagation models are incorporated with various terrain databases and data from other sources, such as the U.S. Census. Adaptations of historic models, and those for more specialized situations have been developed, enhanced, and compared. ITS engineers contribute their propagation modeling expertise to the international and national standards bodies as well.

Areas of Emphasis

ENGINEERING

PCS Applications The Institute participates in the Alliance for Telecommunications Industry Solutions (ATIS) subcommittee G3GRA (Radio Aspects of GSM/3G and Beyond). ITS is now developing PCS interference models for CDMA and W-CDMA. This project is funded by NTIA.

U.S. Coast Guard Rescue 21 Technical Consulting The Institute assisted the U.S. Coast Guard in testing and evaluating its new communication capabilities by acting as a third-party technical consultant. ITS also modeled antennas for the vessel. The project was funded by the U.S. Coast Guard.

ANALYSIS

Telecommunications Analysis Services The Institute provides network-based access to research results, models, and databases supporting applications in wireless system design and evaluation. These services are available to government and non-government customers and are funded by fee-for-use and fee-for-development charges through an on-line CRADA.

Geographic Information System (GIS) Applications The Institute continues to develop a suite of GIS-based applications for propagation modeling and performance prediction studies. This powerful GIS format complements ITS's propagation prediction capabilities nicely. This work is funded by the Department of Defense.

MODELING

Broadband Wireless Standards The Institute develops radio propagation algorithms and methods that improve spectrum usage of wireless systems. Technical standards are prepared that support U.S. interests in 3G broadband wireless systems and are then fed into the ITU-R Study Group 3, Working Parties 3J, 3K, 3L and 3M. The project is funded by NTIA.

Propagation Model Development & Comparisons The Institute compares and harmonizes existing propagation models, to improve their predictive accuracies and reduce the differences between their predictions. ITS is also starting to model a mobile-to-mobile, short-range (less than 2 km) scenario. This project is funded by NTIA.

PCS Applications

Outputs

- Self-interference models for all PCS technologies.
- Technical contributions to industry-supported efforts for predicting, identifying, and mitigating interference related problems.
- Adapted model for use in evaluating adjacent channel systems.

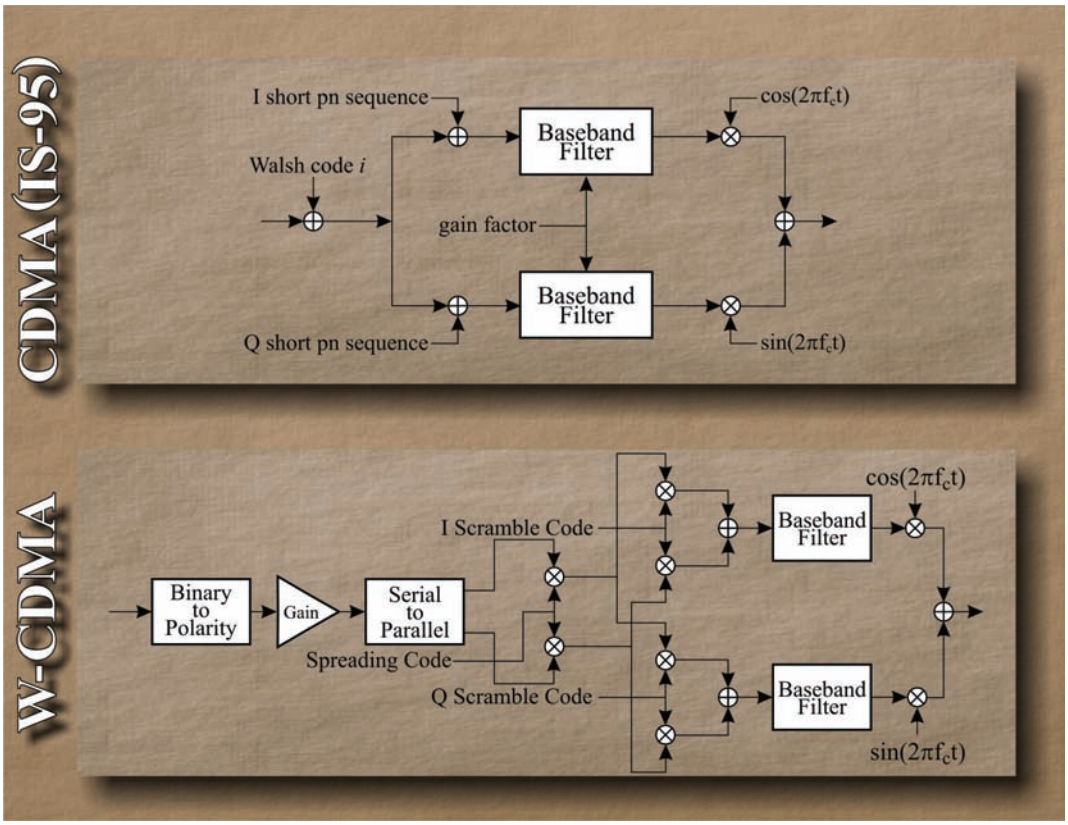
Recent natural disasters have demonstrated how important Personal Communications Services (PCS) have become in establishing emergency communications. These disasters damaged the terrestrial telecommunication system, forcing users to migrate to cellular resources. Emergency responders found themselves unable to establish inter-agency communication links, especially with responders from outside of the affected area and, as a last (or only) resort, relied on cellular systems to fulfill their missions. This sudden influx of traffic by private, commercial, civil, and Federal users resulted in wireless system overloads, a decrease in signal quality, and further disruption of service in the affected area. Beyond the physical damage caused by the events, additional factors contributed to diminished channel capacity of the wireless network, such as co- and adjacent-channel interference and the operation of multiple, independent, non-interoperable systems servicing the same geographical area, often using the same frequency bands and infrastructure (base station sites and towers).

When the infrastructure is damaged or destroyed, one solution to re-establishing communications is to deploy temporary equipment to supplement the surviving system. To make efficient use of limited resources, responders need to know what equipment needs to be deployed in which locations. Knowing the interference issues, dynamics, and load patterns of the original system is key to effective, post-disaster support by national security/emergency preparedness (NS/EP) planners and network operators in an overloaded environment.

In normal, non-disaster situations, increasing demand for wireless voice and data communications requires that the limited spectrum resources allotted to PCS be used as efficiently as possible. Code division multiple access (CDMA) is a major wireless technology used in second generation cellular systems and is becoming even more prominent in third generation systems. Code division schemes make efficient use of allotted spectrum and are relatively unaffected by noise. The capacity of technologies using CDMA is limited primarily by co-channel interference. Most automatic power control schemes in PCS systems increase power levels when the level of interference is unacceptable. This increases the interference level for all users of a common frequency band and can cause an exponential effect where all users of the spectrum are at maximum power levels and experiencing a diminished Quality of Service (QoS). With the increasing dependence on code division technology, a clear understanding of the effects of interference is essential to increase the efficiency of spectrum use.

ITS contributed to the understanding of inter-PCS interference by participating in the Telecommunications Industry Association (TIA) committee TR46.2 (Mobile & Personal Communications 1800-Network Interfaces). As a member of TR46.2, ITS contributed to the development of the Technical Service Bulletin “Licensed Band PCS Interference” (TSB-84A). This bulletin was a first step in characterizing the interfering environment caused by large numbers of active users and competing technologies. Since the completion of TR46.2’s work, coverage of PCS interference concerns has been transferred to the Alliance for Telecommunications Industry Solutions (ATIS) sub-committee WTSC/G3GRA (Wireless Technologies and Systems Committee/Radio Aspects of GSM/3G and Beyond). Work on the successor to TSB-84A is currently underway and ITS continues to be involved in interference issues with this new group.

Work in detecting, identifying, and mitigating co-channel interference requires tools to characterize the interference experienced by PCS air-interface signals. A PCS interference model is a tool that can be used to predict levels and identify sources of interference. Several standard propagation models are accepted by industry members (i.e. Okumura and COST-231/Walfish/Ikegami) but no interference model has been developed or accepted. ITS is developing a PCS interference model capable of implementing any PCS technology, starting with the ANSI/TIA/EIA-95B standard, and progressing to



Downlink diagrams for IS-95 CDMA and W-CDMA as implemented in the PCS co-channel interference model.

technologies proposed for third generation (3G) systems. The model covers system-specific interference modeling to determine co-channel interference from both immediate and adjacent cells. The model produces a representation of an instantaneous air interface signal. The signal can contain outputs of multiple base stations with variable numbers of channels for each base station and can assign relative power levels for each individual channel. Both forward and reverse link processes are included in the model. In addition to the 95B standard, the next-generation W-CDMA (Wideband CDMA) is currently being implemented. The figure shows the block diagrams of the forward data paths for both technologies.

The input for the model is a sequence of binary values. This sequence can be random, but has no requirement to be random. The model calculates each channel's signal contribution separately from all other channel's signals and then adds the processed signal to the other signal contributions to form a composite output signal. The power level for a single channel is an arbitrary gain factor of the baseband filter which is set separately for each channel.

The output of the model consists of a vector of numerical values representing a sampled QPSK or OQPSK signal. There is no error correction added to the input sequence, only spreading codes and modulation processes are used. This model does not check for recovery information contained in the input. Its only purpose is to determine how well the system can transmit the bits of the input binary sequence.

The output of the model is a sampled modulated signal which is the composite of the signals transmitted from all sources identified in a specified scenario. Software- and hardware-based simulations can use the sampled signal from the model to evaluate system designs. These simulations can characterize one-on-one, one-on-many, and many-on-one interference. As a result, potential solutions to congestion can be proposed to solve existing problems or to anticipate and avoid potential problems.

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U.S. Coast Guard Rescue 21 Technical Consulting

Outputs

- Written technical report to evaluate vessel communications capabilities.
- Radio frequency (RF) analysis.
- On-site vessel measurements.

Rescue 21 is a project undertaken by the U.S. Coast Guard (USCG) to modernize and upgrade its current National Distress and Response System (NDRS). This system will enhance the Coast Guard's communication capabilities, increase its response coverage area, provide a common operation environment, and provide USGC personnel with modernized tools to perform their missions. The NDRS is the maritime emergency response (911) system for the coastal U.S. and the communications infrastructure for all USCG coastal missions. Rescue 21 is a hybrid communications system composed of wireless and wired components. Rescue 21 will consist of many operating regions along the U.S. coast and waterways. Each region will have a Group Communications Center (GCC) that is networked to a Search and Rescue Station and several Remote Transceiver Sites.

The USCG entered into an Inter-Agency agreement with ITS to evaluate the simultaneous communications capabilities of the Rescue 21 vessel subsystem. The focus of the investigation was to determine the physical possibility of achieving simultaneous communications (SC) — receiving a distant radio transmission on one channel while simultaneously transmitting on one or more nearby channels. In particular, a major concern of the USCG is the ability to monitor an emergency channel continuously while communicating on other working channels. The result of ITS's investigation was to determine if such a communication system was technically possible given the physical limitations of the 47-foot vessel (see Figure 1 below), and to produce a recommendation to either keep the existing Rescue 21 system (with possible modifications), or replace it with an alternative system.

The focus of the investigation was the following:

(1) Link budget and radio channel isolation specifications necessary to achieve line-of-sight (LoS) communications.

(2) Characterization of the current system, including sources of noise and interference.

(3) Possible methods for reducing interference in the system and increasing radio isolation to meet the specifications defined in (1).

Figure 1. 47-foot Coast Guard vessel (photograph by E.D. Nelson).

Figure 2. ITS staff taking measurements aboard the 47-foot Coast Guard vessel (photograph by C.J. Behm).

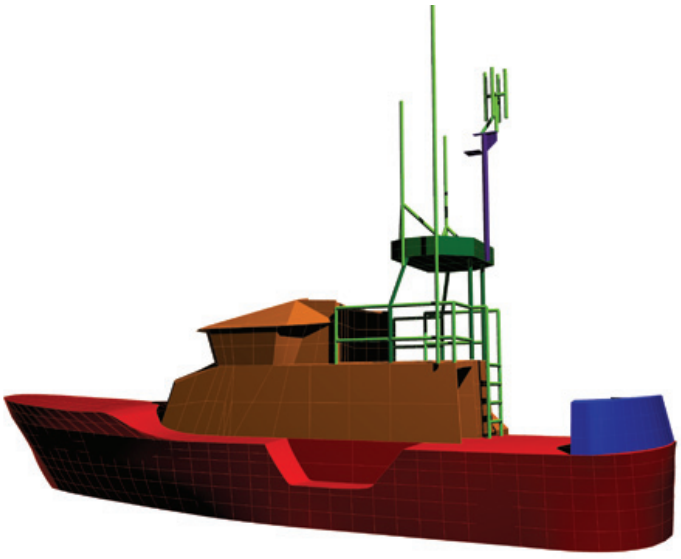

Figure 3. Model of the 47-foot vessel shown in Figure 1.

ITS's technical contributions were focused mainly in the following areas:

***In situ* measurements**

Multiple trips were made by ITS staff to the Atlantic City USCG Station to take measurements on the 47-foot vessel (see Figure 2). These measurements were used to characterize the system radio performance and the noise environment.

Propagation Modeling

In support of the RF coverage analysis, ITS provided the Coast Guard with antenna coverage predictions using the Irregular Terrain Model (ITM) and the Advanced Propagation Model (APM).

Antenna Modeling

A number of different antenna configurations were analyzed on the boat using the 47-foot vessel model in simulation software (see Figure 3).

Findings

(1) Subject to certain constraints, the Rescue 21 system was capable of providing adequate simultaneous communications on two channels between the shore and USCG vessel 47269 at 20 nautical miles.

(2) There are multiple noise sources within the shipboard communication environment that limit the system's simultaneous communications capabilities. If these interferers are eliminated, SC can be achieved.

(3) Simulations indicate that alternative antenna placements would provide increased isolation for the R21 radios.

(4) The current system design can be retained, since it was found to be adequate for the specific simultaneous communications scenario described above.

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Telecommunications Analysis Services

Outputs

- Internet access on a cost reimbursable basis to the latest ITS engineering models and databases for U.S. industry and Government agencies.
- Contributions to the design and evaluation of broadcast, mobile, radar systems, personal communications services (PCS) and local multipoint distribution systems (LMDS).
- Standardized models and methods of system analysis for comparing competing designs for proposed telecommunication services.

The Telecommunications Analysis Services (TA Services) program gives industry and Government agencies access to the latest ITS research and engineering outputs on a cost reimbursable basis. It uses a series of computer programs designed for users with minimal computer expertise or those with in-depth knowledge of radio propagation. The services are updated as new data and methodologies are developed by the Institute's engineering and research programs.

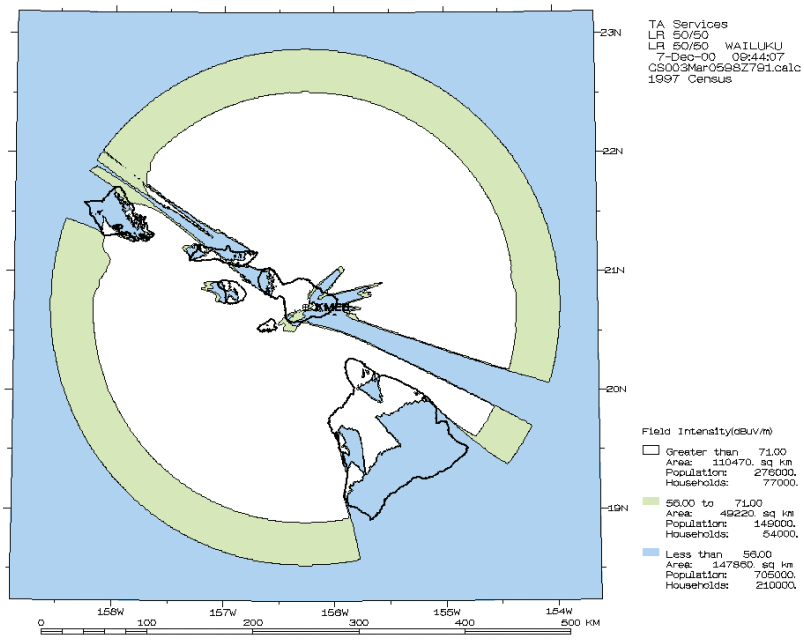


Figure 1. Sample output of the CSPM model of a transmitter located in Hawaii.

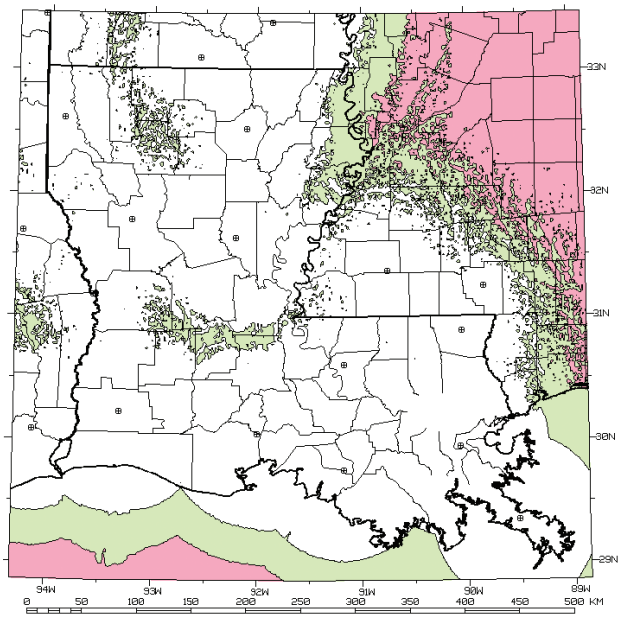
Currently available are: on-line terrain data with 1-arc-second (30m) resolution for CONUS and 3-arc-second (90m) resolution for much of the world, and GLOBE (Global Land One-km Base Elevation) data for the entire world; the U.S. Census data for 1990, 1997 update, and 2000; Federal Communications Commission (FCC) databases; and geographic information systems (GIS) databases (ArcInfo). For more information on available programs, see page 64 of the Tools and Facilities section or call the contact listed below.

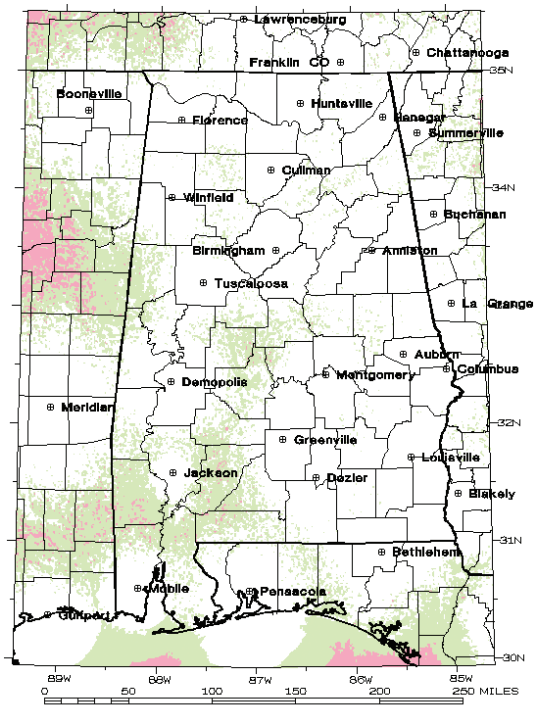
Over the past 20 years, TA Services has developed both generic propagation models for a wide variety of applications in many frequency bands and application specific models used for a particular type of analysis such as High Definition Television (HDTV). These models are placed on the TA Services web access system for use by customers with active accounts on the TA Services system. These customers can activate models, enter information about their broadcast equipment and produce a generic transmitter coverage such as that shown in Figure 1 for a typical broadcast television station using the Communications System Performance Model (CSPM) application program. These coverages follow FCC guidelines and requirements in order to show both the signal coverage and the population that resides within the various analysis contours. Users can also combine many individual transmitter coverages into a composite coverage such as those shown in Figure 2. This allows the user to determine both single transmitter performance as well as integrated system performance.

TA Services has assisted the broadcast television providers of the U.S. with their transition to digital television (DTV) by providing an application specific model for use in advanced television analysis (HDTV, advanced television, and DTV). This model allows the user to create scenarios of desired and undesired station mixes. The model maintains a catalog of television stations and advanced television stations

from the FCC from which these analyses are made. The results of these studies show those areas of new interference and the population and number of households within those areas so that designers can mitigate possible interference situations before they become a problem. The model can also determine the amount of interference a selected station gives to other stations. This allows the engineer to make modifications to the station and then determine the effect those modifications have on the given interference. In addition to creating graphical plots of signal levels, the program creates tabular output which shows the distance and bearing from the selected station to each potential interferer as well as a breakdown of the amount of interference each station in the study contributes to the total interference.

TA Services also has assisted the Public Broadcasting System of the U.S. and the National Weather Service in the determination of their system coverage and public outreach. These two major public providers ensure that more than 95% of all Americans have access to potentially life-saving information in the event of a national crisis of any kind. With the use of the TA Services system and databases, these two national systems were able to improve and verify the coverage of their large diverse systems. This has provided invaluable services to the people of the southeastern portions of the U.S. in this particularly severe hurricane season.





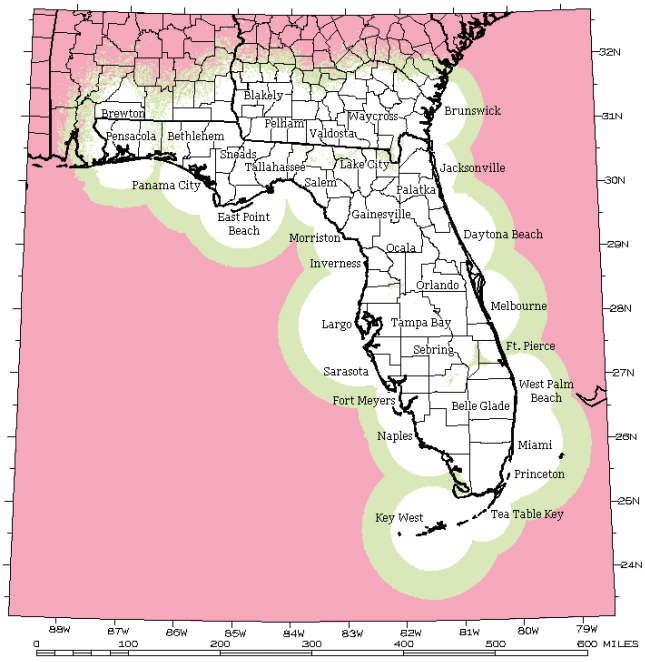


Figure 2. Composite coverage of National Weather Radio for some of the Gulf States (Louisiana, top; Alabama, above; Florida, left). White areas have good coverage, green areas have marginal coverage, and pink areas have signal below the minimum.

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Geographic Information System Applications

Outputs

- Propagation coverages (HF and VHF) for one or more transmitters draped over surfaces.
- Interference and overlap coverages (VHF).
- 2D and 3D visualization environments.
- Fly-through visualization capabilities.

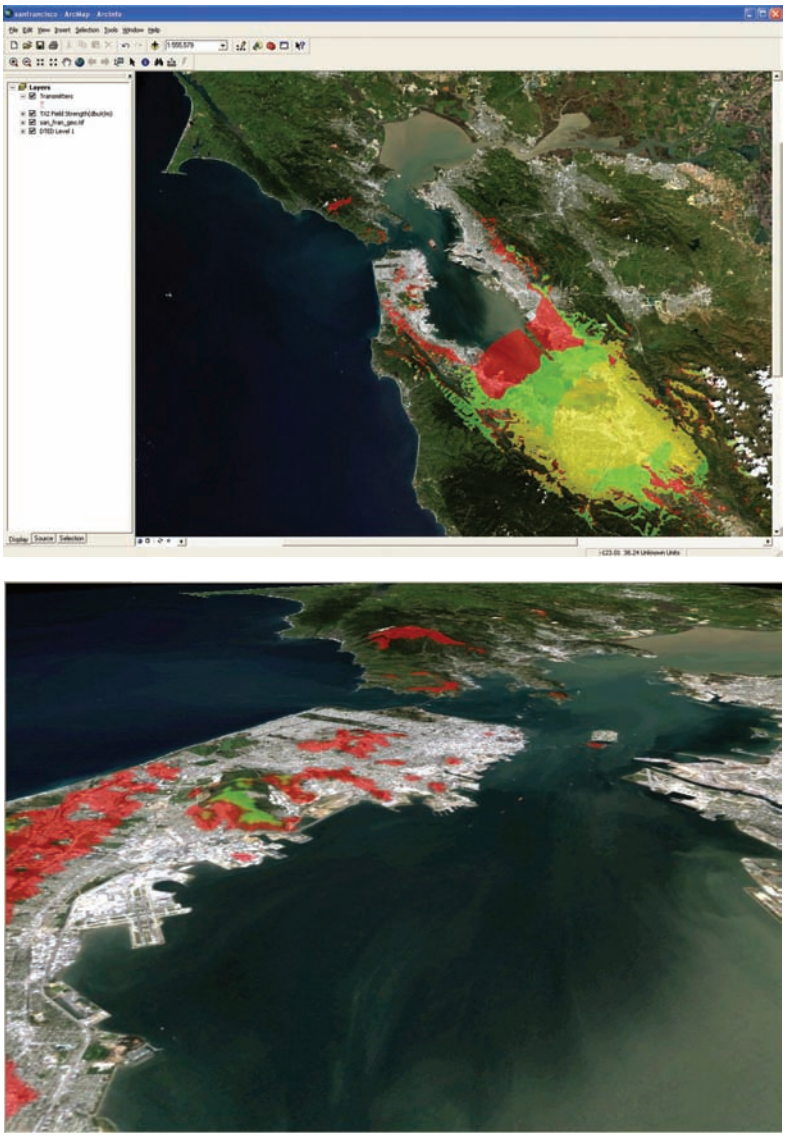

Figure 1. A CSPT-VHF study for San Francisco showing both 2D (top) and 3D (bottom) results.

ITS has developed and continues to improve a suite of Geographic Information System (GIS) based applications incorporating propagation models for outdoor and indoor analyses. Databases for GIS use, including terrain, satellite and aircraft imagery, roads and other transportation infrastructure layers, building data and population, are becoming more available and affordable. These databases can be easily connected to GIS systems and can be shared among users in web-based or standalone GIS applications. The Institute has developed generic and application-specific GIS programs that aid Government agencies, private cellular companies, public and private television stations, transportation companies, and consultants in the performance of their missions to efficiently manage the U.S. telecommunications infrastructure.

One GIS-based tool developed by ITS is the Communication Systems Planning Tool (CSPT-VHF). CSPT is a menu- and icon-driven propagation model developed for frequencies from 20 MHz to 20 GHz that allows the user to connect to a variety of image catalogs and terrain libraries that cover most of the world. The user can create specific analysis areas using these catalogs and libraries and can then perform propagation scenarios for his/her application. These applications can range from outdoor coverage studies of large-scale areas of hundreds of square miles to indoor propagation studies of one building in an urban environment. Figure 1 shows a sample case of a transmitter coverage of the San Francisco Bay, shown in both 2D and 3D. CSPT allows the user to transition into 3D and fly through the environment.

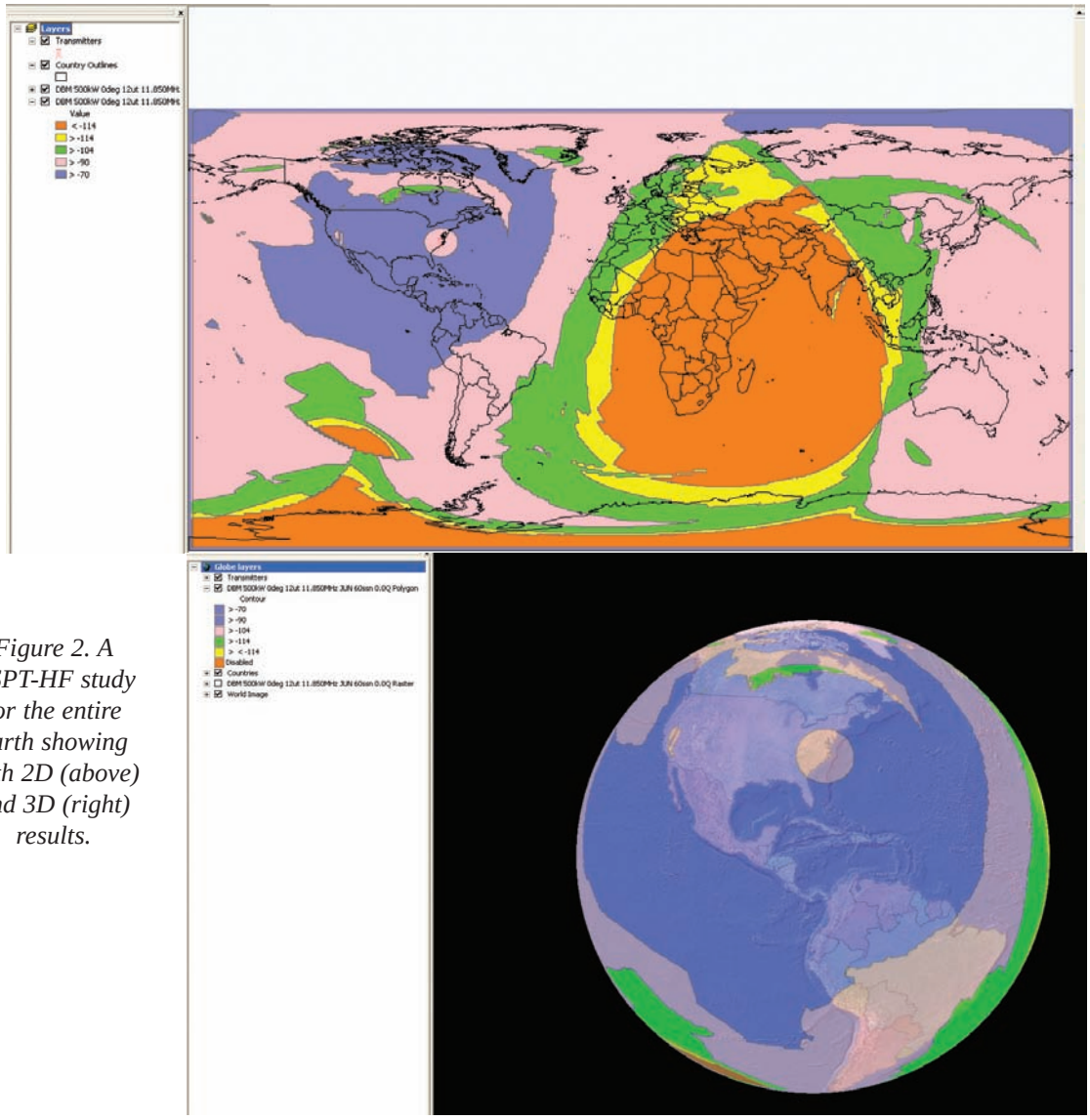

Figure 2. A CSPT-HF study for the entire earth showing both 2D (above) and 3D (right) results.

A second tool is the CSPT-HF model which provides the user with a GIS front end and back end to the ITS HF ICEPAC model. The GIS tool allows the user greater flexibility in creating scenarios for HF area coverage studies. These studies are not limited to nine scenarios as in the ICEAREA model. The output results of ICEPAC are imported into the GIS tool and can be displayed in 2D or 3D, as shown in Figure 2.

The general flow of the CSPT GIS tool is as follows. The user defines an area within which a study will be performed. This analysis area can be defined graphically by zooming into a map of the world or of the U.S. or by defining the latitude and longitude of the boundaries of the desired area. The user then imports desired GIS information such as political boundaries, roads, rivers, special imagery, or application-specific GIS data. After creating the analysis area, the user creates or imports transmitter, receiver, and antenna data. Lastly, the user selects the type of coverage and the propagation model to be used in the analysis.

Coverages, composites, and interference analyses can be imported into GIS visualization tools allowing the user to see and often fly through their studies so that a better understanding of the analysis results can be obtained.

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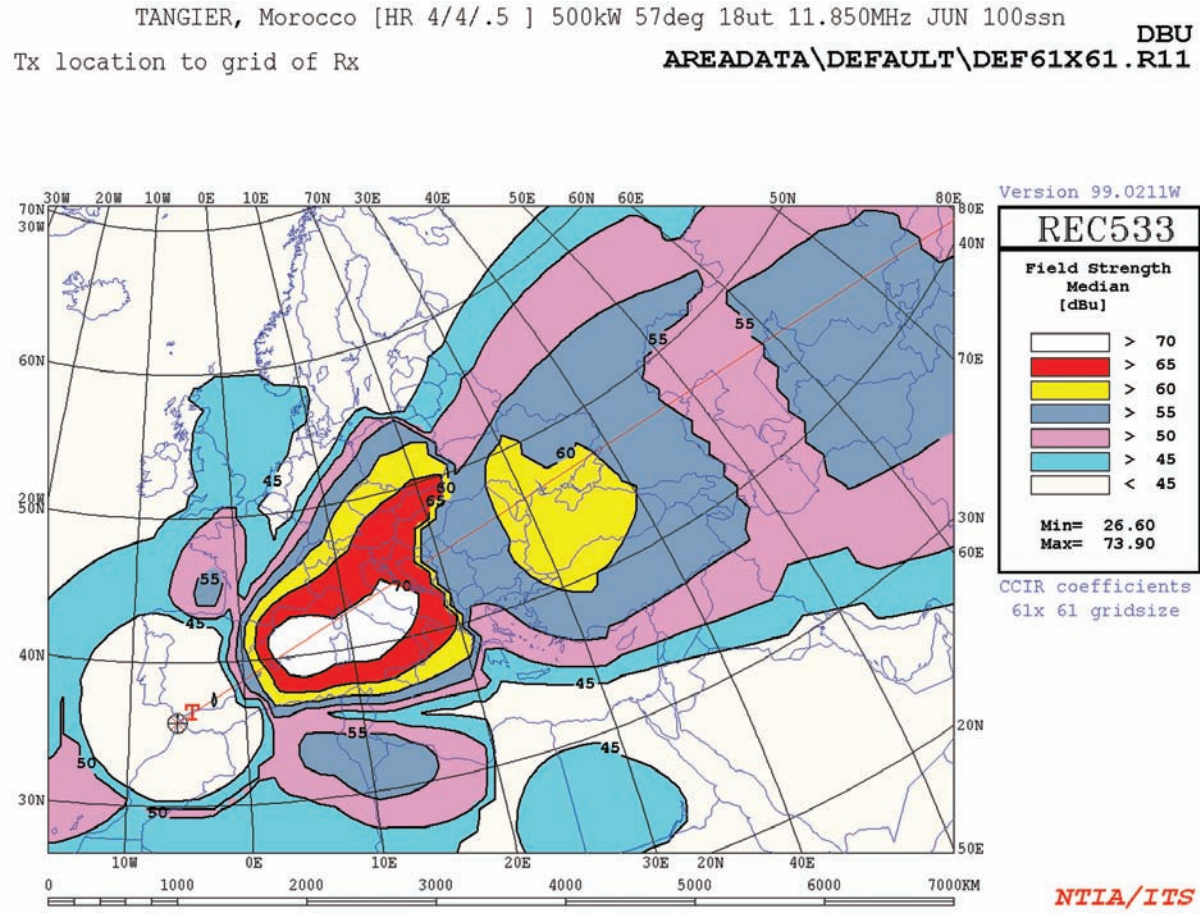
Broadband Wireless Standards

Outputs

- Preparation of technical standards and documents for the ITU-R that support the U.S. interest in broadband wireless systems.
- Development of new radio propagation algorithms or methods that improve spectrum usage of wireless systems.

Wireless communication has seen tremendous growth in recent years, in both the number of users and the types of new services. In particular, there has been an emphasis on Internet and broadband data uses, over and above voice applications. These additional users and services require greater bandwidths than before, which for wireless users means more radio spectrum. As growing numbers of users require ever more spectrum, it is necessary to be able to predict signal coverage for various wireless services more accurately, so that inter-service spectrum sharing can occur without causing harmful interference to incumbents and new users/services. The development of radio-wave propagation prediction models for accurate prediction of signal coverage supports standards for these broadband wireless systems.

Historically, radio propagation model development tended to be very service specific, with models for the broadcast FM radio and television service or for the land mobile radio service, and little or no overlap in applicability between the models for different services. This service-specific approach was adequate for a regulatory philosophy that assigned



Output from the High Frequency propagation software for international frequency coordination, developed by the ITU and maintained by ITS.

different, exclusive blocks of the radio spectrum to different services in a proprietary fashion. However, this lack of overlap between models can also create an impediment to the shared use of spectrum by different services or wireless applications, because, for example, a model that is used to predict intra-service system availability and interference might not apply flexibly and accurately to inter-service interference predictions. To overcome this problem, ITS and other research organizations have been developing and evaluating propagation models to predict wireless signal coverage more accurately and flexibly, both within and across services.

ITS participates in the international development of radio propagation prediction model standards that can be used by spectrum managers and system planners of land mobile, terrestrial broadcast, maritime mobile and certain applicable fixed (e.g., point-to-multipoint) services, among others. ITS supports this effort by participation in the International Telecommunication Union's Radiocommunication Sector (ITU-R) Study Group 3 (Radiowave Propagation). The most recent meetings of the Working Parties (WP) of Study Group 3, held in Cleveland, Ohio, in late September and early October, 2005, were jointly sponsored by the National Aeronautics and Space Administration (NASA) and ITS. Four ITS engineers participated in these meetings as members of the official U.S. delegation.

Study Group 3 recently developed and adopted a radio propagation model which blends features that the different services had used independently, thereby clarifying and unifying planning and coordination activities across these services. This recommendation, Rec. ITU-R P.1546, is usually considered to be a site-general model, although for improved accuracy it specifies numerous adjustments and corrections to the basic method that are very nearly site-specific in their application. Numerous aspects of Rec. ITU-R P.1546 have been adopted by the Regional Radio Conference (RRC-04)[1] as the basis for planning and coordination studies within the Conference's planning area. To support the work of the Intersessional Planning Group (IPG) and to prepare for the second and final meetings of the Conference (RRC-06), Study Group 3, WP 3K (point-to-area propagation) and, in particular, Subgroup 3K-2, have undertaken a number of revisions to the Recommendation. For several years, an ITS engineer has served as chairman of Subgroup 3K-2.

As a much needed adjunct to this work, Subgroup 3K-1 of WP 3K is examining five proposed site-specific models for intra- and inter-service planning and coordination uses, when detailed terrain elevation data are available. Two of these models, the ITS Irregular Terrain Model (ITM) and a closely related hybrid model based on Recommendations ITU-R P.1546 and P.452, originated in contributions to WP 3K from the U.S. Administration which were authored by ITS. ITS has established a password protected worldwide website for participants in Subgroups 3K-1 and 3K-2 to exchange propagation measurement data and terrain profiles for use in testing and comparing these models. As part of this testing and comparison effort, ITS will contribute model source code and U.S. radio propagation measurement data.

In addition to the above areas, WP 3K deals with propagation aspects of short-path personal communications and wireless local area networks in the frequency range 300 MHz to 100 GHz in Subgroups 3K-3 and 3K-4, both of which are longstanding. At the most recent meetings of WP 3K, the Chairman of WP 3K established a new subgroup, Subgroup 3K-5, to address ultrawideband radio signal propagation. Based on a U.S. contribution authored by ITS, a draft new recommendation on ultrawideband propagation was extensively improved and revised.

ITS also participates in the work of Working Parties 3J (propagation fundamentals), 3M (point-to-point propagation, earth-space propagation and interference and coordination) and 3L (ionospheric propagation). ITS continues to be responsible for maintaining the HF (3-30 MHz) propagation software developed by the ITU-R for international frequency coordination. The ITU-R website, http://www.itu.int/ITU-R/software/study-groups/rsg3/databanks/ionosph/index.html links to an ITS website for HF propagation models for the authoritative source code for HF sky-wave propagation (Rec. P.533). This website also makes two ITS developed HF propagation models, ICEPAC and VOACAP, available for downloading. An example of the type of output that the Rec. P.533 software can produce is shown in the figure.

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[1] The RRC-04 is the first of two scheduled sessions of the international conference to establish agreements and standards for the coordination and planning of digital terrestrial broadcast services (radio and television) in parts of the ITU-R's Regions 1 and 3 of the world.

Propagation Model Development & Comparisons

Outputs

- Improvement of the effective height algorithm in the ITS Irregular Terrain Model (ITM).

The propagation model development effort continued the focus on improvements to the algorithm for determining the effective antenna heights within the ITS Irregular Terrain Model (ITM) in its point-to-point mode. The effective antenna heights determine a number of important intermediate quantities that are very influential in the prediction of the computed reference attenuation in the ITM, notably the smooth earth horizon distances and, in the case of line-of-sight paths, the radio horizon distances and horizon elevation angles. In the ITM, the sum of the smooth earth horizon distances determines the point at which the line-of-sight range attenuation curve is matched to the diffraction range attenuation curve. The radio horizon distances and elevation angles are used, among other things, to determine the values of the attenuation curve in the diffraction range. For any given transhorizon path, frequency of operation and polarization, higher effective heights will tend to yield less predicted attenuation than lower effective heights. For "short" line-of-sight paths and moderately flat terrain, however, there is the possibility of constructive and destructive interference between the direct ray and the ray reflected from the ground as the dominant propagation mechanism, so reduction in attenuation is not necessarily strictly monotonic with increasing effective heights.

For transhorizon paths the direct ray between the terminals' structural heights does not clear the intervening terrain, so the radio horizon distances and horizon elevation angles are determined from the highest visible (as seen from each terminal's structural height in the direction of the geodesic between the terminals) terrain point (for single horizon paths) or points (for double horizon paths) on the terrain profile between the terminals. For line-of-sight paths the direct ray between the terminals' structural heights clears the intervening terrain, so these quantities are undefined. To circumvent this difficulty, the ITM algorithm falls back to the method used in its area prediction mode, that is, the radio horizon distances and elevation angles are set empirically, using the observed medians of these quantities. The observed median radio horizon distances are monotonically increasing functions of the effective heights, and the observed median horizon elevation angles are monotonically decreasing functions of the radio horizon distances.

In the area prediction mode of the ITM, the path distance is a parameter. In contrast, in the point-to-point mode of the ITM, the path distance is a given for the path in question. Therefore, to complete the definition of the radio horizon distances and elevation angles for line-of-sight paths in the point-to-point mode, the sum of the radio horizon distances is compared to the path distance. If this sum is less than the path distance, which implies that the path is transhorizon, as opposed to line-of-sight, then the effective heights are increased by a factor designed to increase the sum to be just greater than or equal to the path distance. That is, it is assumed that the original estimates of the effective heights were too low for the inferred radio horizon distances to be consistent with the line-of-sight category and that, in consequence, these effective heights should be increased. In this instance, the radio horizon distances and elevation angles are also recomputed, based on the increased effective heights.

Figures 1 and 2 illustrate the differences in the ITM's predictions between two methods of estimating the effective antenna heights. Figure 1 shows predicted field strengths (dB μV/m) using the current ITM point-to-point mode algorithm for estimating the effective antenna heights around a notional transmitter site near Denver, Colorado. Figure 2 shows the same predicted field strength levels as Figure 1 for the same site, but with the effective antenna heights fixed at the structural heights, regardless of the comparison between the sum of the inferred radio horizon distances and the path distance. A comparison of the two figures reveals that fixing the effective heights at the structural heights yields a more conservative prediction. This result is not too surprising, since the current ITM algorithm for estimating the effective antenna heights always yields estimates that are greater than or equal to the structural heights.

During the previous year's effort, it was evident that considerable accuracy improvement over the current algorithm could be obtained for transhorizon paths, if one were to locate and fit the terrain in the vicinity of the point(s) of minimum Fresnel clearance on the terminal's immediate foreground (i.e., the terrain between the terminal in question and its radio horizon) and extrapolate that fit to the terminal's location. Unfortunately, this approach was not nearly so fruitful when applied to the full terrain profile on line-of-sight paths. One possible reason for this is the close coupling between the effective heights and the radio horizon distances and elevation angles for line-of-sight paths.

In order to overcome this coupling for line-of-sight paths, some method of determining the radio horizon distances and elevation angles on these paths is required. If one uses the same definition for these quantities that is applied to transhorizon paths, but extends the terrain which is considered to the geodesic beyond the terminals, then it is clear that these always exist. Furthermore, the sum of these radio horizon distances will always be greater than or equal to the path distance. This modification to the line-of-sight algorithm has been implemented and some initial testing/comparison to measured propagation data has been carried out. The results are encouraging, but it is expected that some additional refinements to the effective height algorithm will yield further predictive accuracy improvements.

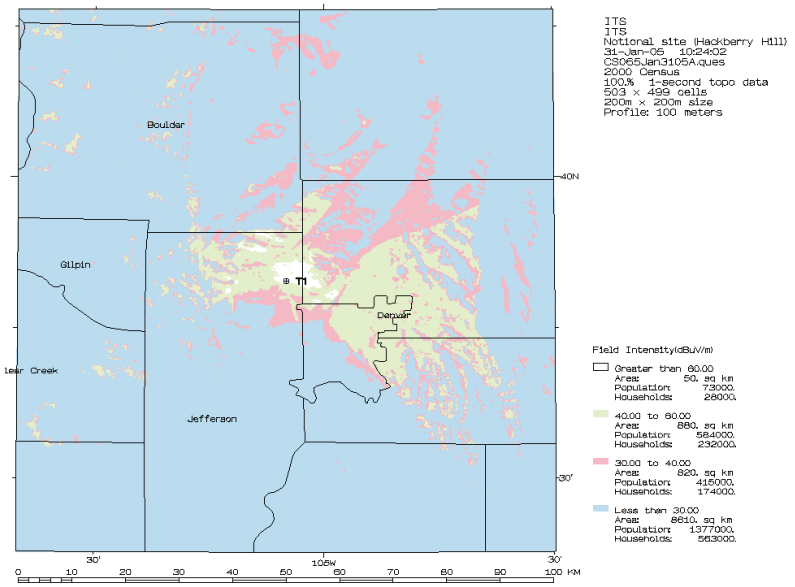

Figure 1. Communication System Performance Model (CSPM) plot showing predicted radio coverage using ITM with the existing effective height algorithm.

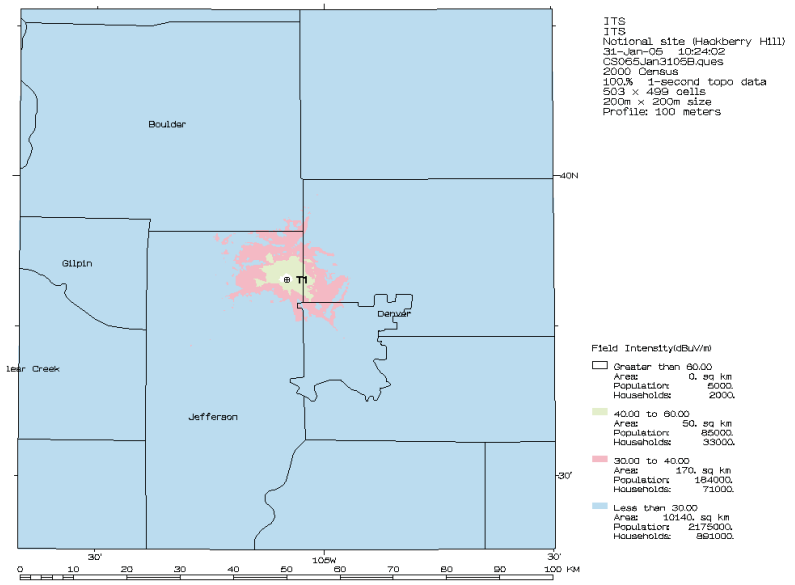

Figure 2. CSPM plot showing predicted radio coverage using ITM with effective heights set to the structured height above ground.

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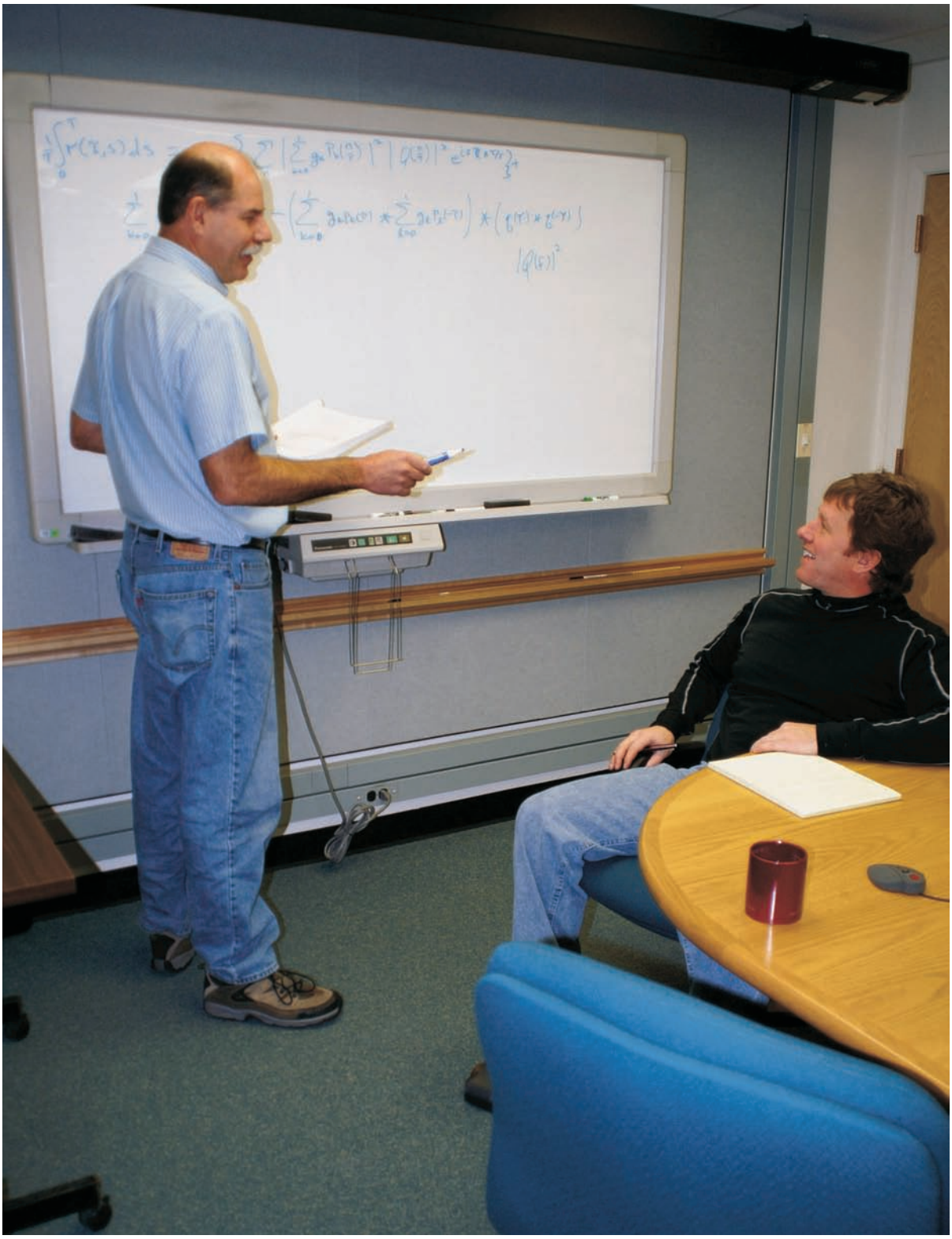

Two engineers in the ITS Telecommunications Theory Division discussing their mathematical analysis of the effects of ultrawideband interference on the performance of a satellite receiver (photograph by F.H. Sanders).

Telecommunications Theory

The explosive growth of telecommunications traffic in recent years continues to generate ever-increasing demands for radio spectrum while greatly increasing the loading of many telecommunications networks, both wireless and wireline. Yet the radio spectrum is a limited resource. In response to these realities, new radio technologies are being developed and implemented to use spectrum more efficiently and effectively. Also, the basic paradigm of radio spectrum management is beginning to move away from traditional, top-down frequency-assignment methods and is migrating toward autonomous, interference-limited technologies that allow dynamic reassignment of radio frequencies. But to fulfill the promise of more autonomous, locally self-controlled spectrum use schemes, the effects of noise and interference on radio receiver performance must be thoroughly understood, and such knowledge must be focused on improvements in the performance of both existing and new networks. Tools to monitor the quality of audio and video information on communication channels also must be developed and used so that audio and video quality levels can be accurately adjusted in real-time to achieve maximal quality with minimal use of available bandwidth.

To achieve these goals for the U.S. Government as well as the private sector, the Telecommunications Theory Division performs research in both wireless and wireline telecommunications, seeking to understand and improve telecommunications at the most fundamental levels of physics and engineering. Strong ongoing investigations are being maintained in the major areas of broadband wireless systems performance; advanced antenna designs; noise and interference as critical limiting factors for advanced communication systems; audio and video quality assessment; advanced spectrum sharing concepts; and radio propagation.

Through technical publications, cooperative research and development agreements (CRADAs), and interagency agreements, ITS transfers the results of its work in all these technology areas to both the public and private sectors, where the knowledge is transformed into better telecommunications for the United States, new and better products for consumers and the Government, and new opportunities for economic development and growth for the economy.

Areas of Emphasis

Audio Quality Research
The Institute conducts research and development in coding, transmission, and perception-based quality measures for voice and other audio communication systems. Projects are funded by NTIA.

Broadband Radio Research and Propagation Measurements
The Institute conducts an ongoing program of radiowave propagation research and measurements, using the ITS Mobile Radio Propagation Measurement Facility and the Digital Sampling Channel Probe (DSCP). Using these facilities, researchers can determine propagation conditions and impairments which affect new digital communication systems and answer questions regarding the viability of proposed radio services. The project is funded by NTIA.

Effects of Radio Channel on Receivers
The Institute, a recognized leader in radio channel measurement and modeling, is conducting research to assess the effects of interference and noise on the performance of radio receivers and networks. Recent work has focused on the effects of noise and interference as limiting factors in system performance. The project is funded by NTIA.

Video Quality Research
The Institute develops perception-based, technology-independent video quality measures and promotes their adoption in national/international standards. Projects are funded by NTIA.

Audio Quality Research

Outputs

- Technical publications and presentations on new research results.
- Measurements and estimates of speech and audio quality and algorithm performance.
- Algorithms and data supporting speech and audio coding and quality assessment.

Digital coding and transmission of speech and audio signals are enabling technologies for many telecommunications and broadcasting services including cellular telephone services, voice over Internet protocol (VoIP) services, and digital audio broadcasting systems. Speech and audio signals can be coded and transmitted at low bit-rates with good fidelity. In addition, coded speech and audio signals can be packetized for transmission, thus sharing radio spectrum or wired network bandwidth with other data streams and hence with other users.

Innovation in digital coding and transmission involves compromises and trade-offs among speech or audio quality, transmission bit-rate, robustness to transmission errors and losses, coding and transmission delay, and coding and transmission algorithm complexity. The ITS Audio Quality Research Program works to identify and develop new techniques to increase quality or robustness, or to lower bit-rate, delay, or complexity of digital speech and audio coding and transmission algorithms. The ultimate result of such advances is better sounding, more reliable, more efficient communications and broadcasting services.

The robustness of digital coding and transmission algorithms is critical in applications that use lossy channels such as those associated with wireless systems and those provided by the Internet. In FY 2005, Program staff have continued to work towards more robust speech coding through a method called multiple-descriptive coding (MDC). In MDC an encoder forms multiple partial descriptions of a speech signal and these descriptions are sent over different channels. If all descriptions arrive at the decoder intact, a higher-quality reconstruction of the speech is possible. If channel failures cause any of the descriptions to be lost, then a lower-quality reconstruction of the speech signal is still possible.

Program staff developed and tested a multiple description pulse code modulation (PCM) speech coding system that exploits naturally occurring correlations between adjacent samples of speech and invokes a pair of appropriately designed vector quantizers. This system includes an aspect ratio parameter that allows one to trade off the speech quality when one channel is working against the speech quality when two channels are working. This in turn allows one to match the channel conditions to maximize speech quality.

Even when robust coding techniques such as MDC are deployed, time-varying channel conditions generally will cause end users to experience time-varying speech quality. But the perception of time-varying speech quality is not yet well-understood. For example, which would be preferable: speech that fluctuates between high quality and low quality, or speech that is consistently of medium quality? How would the preference change with the levels of high, medium, and low quality? And how would the preference change with the timing and nature of the quality fluctuations?

Program staff recently designed, conducted, and analyzed an experiment to characterize one simple yet fundamental component of time-varying speech quality. In this experiment, subjects heard recordings where speech quality changed twice, resulting in speech quality histories of the form “low, high, low” and “high, low, high.” Figure 1 below shows an example result from this experiment. The vertical

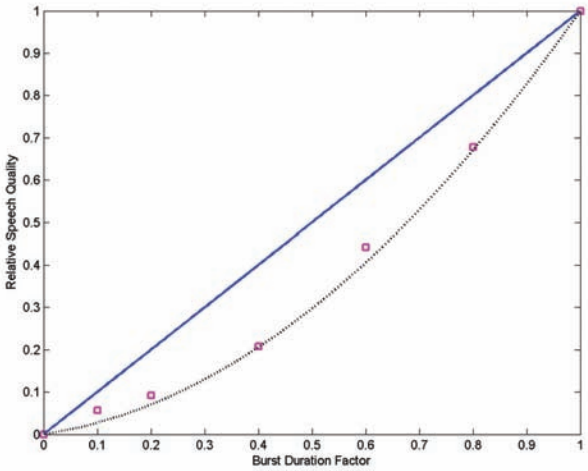

Figure 1. Example results from an experiment on time-varying speech quality. See text for details.

axis represents overall speech quality as judged by the subjects in the experiment. Here 0 represents low speech quality and 1 represents high speech quality. On the horizontal axis, the burst duration factor describes the fraction of the time that the recording has speech quality 1. (The remainder of the time the recording has speech quality 0.) If subjects judged overall speech quality by simply averaging instantaneous speech quality, then their responses would grow linearly as described by the solid blue line in the figure. Instead, subjects' responses fall below this line, as denoted by purple squares and approximated by the dotted black line in the figure. This indicates that subjects use a process that is more critical than simple averaging when judging overall speech quality. Periods of low and high quality do not balance out in the mathematical sense; rather, periods of low quality seem to carry more weight than periods of high quality. In this sense, we might say that listeners are pessimists when it comes to speech quality.

Figure 2. Subjective speech and audio testing can now be controlled by test participants using wireless PDAs (photograph by S. Wolf).

In FY 2005, Program staff designed, installed, and tested upgrades and new capabilities to the ITS Audio-Visual Laboratories. One major upgrade provides greatly enhanced flexibility for subjective test design and operation, in that subjective tests can now be controlled through a very flexible, powerful, and easy to use, high level language that is well-integrated with digital and analog audio I/O, computer graphics display, text display, text entry, and mouse input. Graphical display and mouse input is extended from a host desktop computer (operated by Program staff) to a handheld personal digital assistant (PDA) (operated by a subjective test participant). This extension is enabled by a wireless local area network (LAN) so that test participants only need to operate a single familiar, intuitive, lightweight, wireless device (see Figure 2 above).

Throughout FY 2005, program staff continued with subjective and objective audio quality testing to support this and other ITS programs. Staff continued to transfer technologies to industry, Government, and academia through numerous technical publications, presentations, guest lectures, laboratory demonstrations, and by completing peer reviews for technical journals and workshops. Program staff also incorporated recent program results into a revision of an American National Standard: ANSI T1.801-04. This telecommunications standard is titled "Multimedia Communications Delay, Synchronization, and Frame Rate," and it now includes the specification of an ITS-developed algorithm for tracking variable transmission delay across a wide range of speech coding conditions. Program publications, technical information, and other program results are available at http://www.its.bldrdoc.gov/audio.

Recent Publications

S.D. Voran, "A multiple-description PCM speech coder using structured dual vector quantizers," in *Proc. International Conference on Acoustics, Speech and Signal Processing*, Philadelphia, Mar. 2005.

S.D. Voran, "Multiple-description PCM speech coding by complementary asymmetric vector quantizers," in *Proc. IEEE Region 5 Conference*, Boulder, CO, Apr. 2005.

S.D. Voran, "A basic experiment on time-varying speech quality," in *Proc. 4th International MESAQIN (Measurement of Speech and Audio Quality in Networks) Conference*, Prague, Czech Republic, Jun. 2005.

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Broadband Radio Research and Propagation Measurements

Outputs

- Study of MIMO antenna systems and information theory relating to MIMO systems.
- Study of relative propagation impairments between 2.4 GHz ISM band and 5.8 GHz communications band.

An ongoing program of radiowave propagation research and measurements is supported using the ITS Mobile Radio Propagation Measurement Facility and the Digital Channel Probe. By using these facilities, researchers have the ability to determine propagation conditions and impairments which affect new digital communication systems and answer questions regarding the viability of proposed radio services.

The system has been configured to study the relative propagation impairments between the 2.4-GHz ISM band and the recently allocated 5.8-GHz communications band. Mobile data was collected in an urban environment and the relative impairments were quantified. This data is intended to help system designers of next generation systems in the 5.8-GHz band determine the relative power requirements and link budgets needed versus systems in personal communications services (PCS) and cellular bands. It will also help promote commercial high frequency spectrum use and frequency extension.

More recently the system was configured to quantify the propagation conditions in a reverberation chamber (Figures 1 and 2). These data were collected to determine the suitability of the chamber for comparative performance testing of multiple-input multiple-output (MIMO) communication systems.

Figure 1. Test equipment configured for 4 channel operation at 2.4 GHz for NIST reverberation chamber characterization (photograph by F.H. Sanders).

Figure 2. MIMO test setup in NIST reverberation chamber. Antennas configured for single input single output measurement (photograph by F.H. Sanders).

Recent Publications

J.J. Lemmon, "Radiation pattern analysis of a four-element linear array," NTIA Technical Memorandum TM-05-426, Aug. 2005.

J.J. Lemmon, "MIMO channel capacity with discrete alphabets," in *Proc. Wireless 2005*, Calgary, Jul. 2005.

P. Papazian, "Basic transmission loss and delay spread measurements for frequencies between 430 MHz and 5750 MHz," *IEEE Transactions on Antennas and Propagation*, Feb. 2005.

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Effects of Radio Channel on Receivers

Outputs

- Analysis of bit, frame, and packet transmission reliability.
- Correlations between radio channel characteristics and receiver performance.
- Radio channel measurement requirements for receiver performance analysis.

Telecommunications play a vital role in many of the services deemed essential for modern life. For many of these services, telecommunication is provided over a radio link. Land mobile, indoor, and satellite are but a few examples of radio links commonly used. The radio link consists of a transmitter, receiver, and the channel separating the two. The radio channel is often the primary impediment to fast and reliable telecommunication. Hence, the Institute has historically focused most of its efforts towards understanding the radio channel. This project builds upon these historical strengths by studying the effects of the channel on receiver performance. Figure 1 summarizes the scope of this project.

This study requires expertise in a wide range of radio engineering disciplines. For example, this study requires detailed knowledge of receiver demodulation and signal processing methods. This is a formidable challenge considering the large number of legacy receivers and the growing numbers of receivers for emerging technologies such as personal communications services (PCS), wireless local area networks (WLAN), and global positioning system (GPS). Complexity of these receivers ranges from mere analog demodulation to digital demodulation with advanced signal processing methods including multipath equalization and error correction techniques.

This study also requires extensive knowledge of the radio channel. The radio channel is often characterized by propagation phenomena such as multipath and loss, additive noise from natural and man-made radiators, and signals from other radio links. These radio channel components affect each radio receiver uniquely. For example, PCS receivers operating in a residential neighborhood in the 1900-MHz band are primarily compromised by time-varying multipath introduced by buildings and terrain. WLAN receivers operating within buildings in the 900-, 2400-, and 5800-MHz industrial, scientific, and medical bands contend with man-made radio noise radiated by other electrical devices such as microwave ovens, in addition to multipath introduced by reflections and scattering from walls, ceilings, and objects within the room. GPS and other satellite broadcast receivers are hindered by terrestrial radio links whose signals occupy the same frequencies.

Receiver performance evaluation includes analysis of bit and frame transmission error rates. This analysis can be extended to packet transmission error rates across a network incorporating radio links. Performance evaluation metrics such as these are correlated against radio channel parameters, e.g., multipath channel root mean square delay spread, man-made noise impulsiveness, or interfering signal

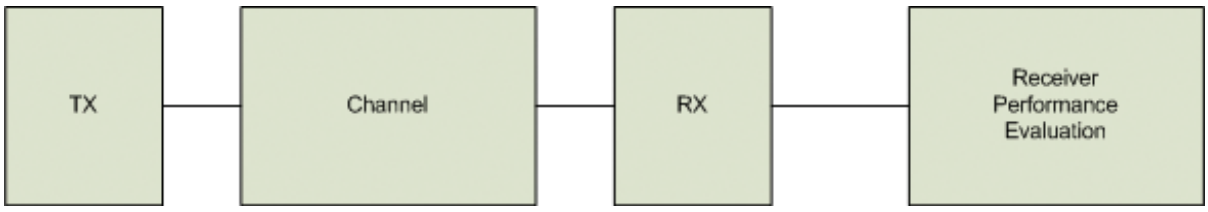

Figure 1. Scope of project includes the study of channel, receiver, and various methods of receiver performance evaluation.

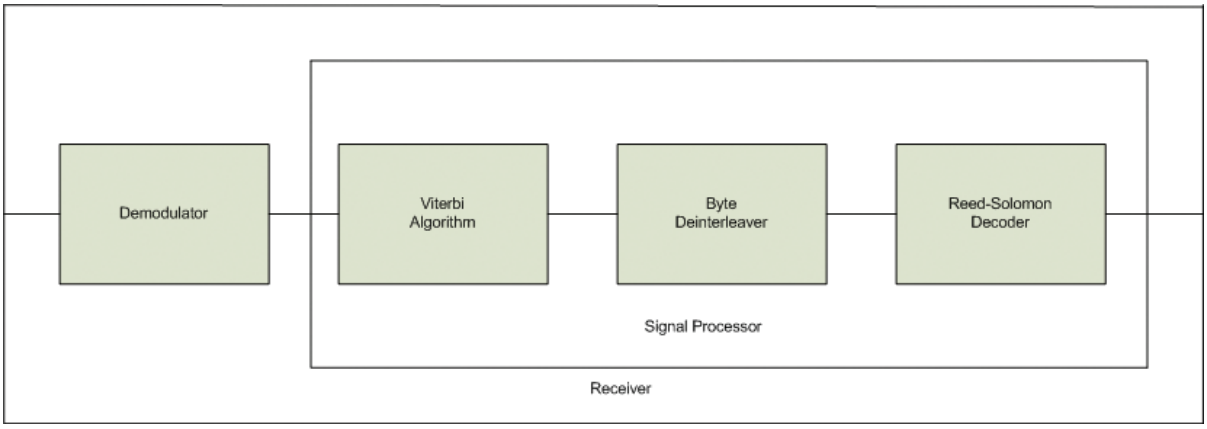

Figure 2. Block diagram of a direct broadcast satellite receiver highlighting demodulation and signal processing tasks.

level crossing rates. In addition, a considerable amount of effort is expended statistically analyzing the effect measurement uncertainties have on the performance metrics and subsequent analysis.

Success of this project is dependent on knowing the limitations of radio channel characterization measurement and analysis and how these limitations influence the study of the effects of the radio channel on the receiver. These subtleties are addressed by project personnel who have performed many of these measurements and analyses themselves and who continue to have close working relationships with those currently performing them. Project personnel are also well versed in analysis of random processes which are used to characterize radio channels and transmitted signals.

In FY 2005, project personnel focused on two primary tasks. The first task supported research within the Institute on the effects of gated Gaussian noise signals on direct broadcast satellite receiver performance. A block diagram of the direct broadcast satellite receiver with associated demodulator and signal processing components is shown in Figure 2. We supported this research by verifying measurements of the susceptibility to continuous Gaussian noise analytically and gated-Gaussian noise through simulation. We also verified gated-Gaussian noise amplitude probability distribution and the power spectral density characterization measurements. Verification of the APD measurement was critical since the effects of interferring signals on receiver performance are often correlated to the peak to average power ratio provided by the APD.

The second task concerned the calculation of the uncertainties of radio channel characterization measurements. These uncertainties are rarely reported in professional journal articles. Our goal is to describe how the uncertainties are computed from a finite sample set and show how they can be used in multipath, man-made noise, and signal characterization measurement analysis. In the future, these uncertainties will be translated to receiver performance parameters.

Recent Publications

M. Cotton, R. Achatz, J. Wepman, and P. Runkle, "Appendix B: Verification of susceptibility results" in "Interference potential of ultrawideband signals - Part 2: Measurement of gated-noise interference to C-band satellite digital television receivers," NTIA Report TR-05-429, Aug. 2005.

R. Dalke, "Statistical considerations for noise and interfering characterization measurements," NTIA Report, in progress.

R. Dalke and G. Hufford,"Analysis of the Markov character of a general Rayleigh fading channel," NTIA Technical Memorandum TM-05-423, Apr. 2005.

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Video Quality Research

Outputs

- Digital video quality measurement technology.
- Journal papers and national/international video quality measurement standards.
- Technical input to development of U.S. policies on advanced video technologies.
- A national objective and subjective digital video quality testing laboratory.

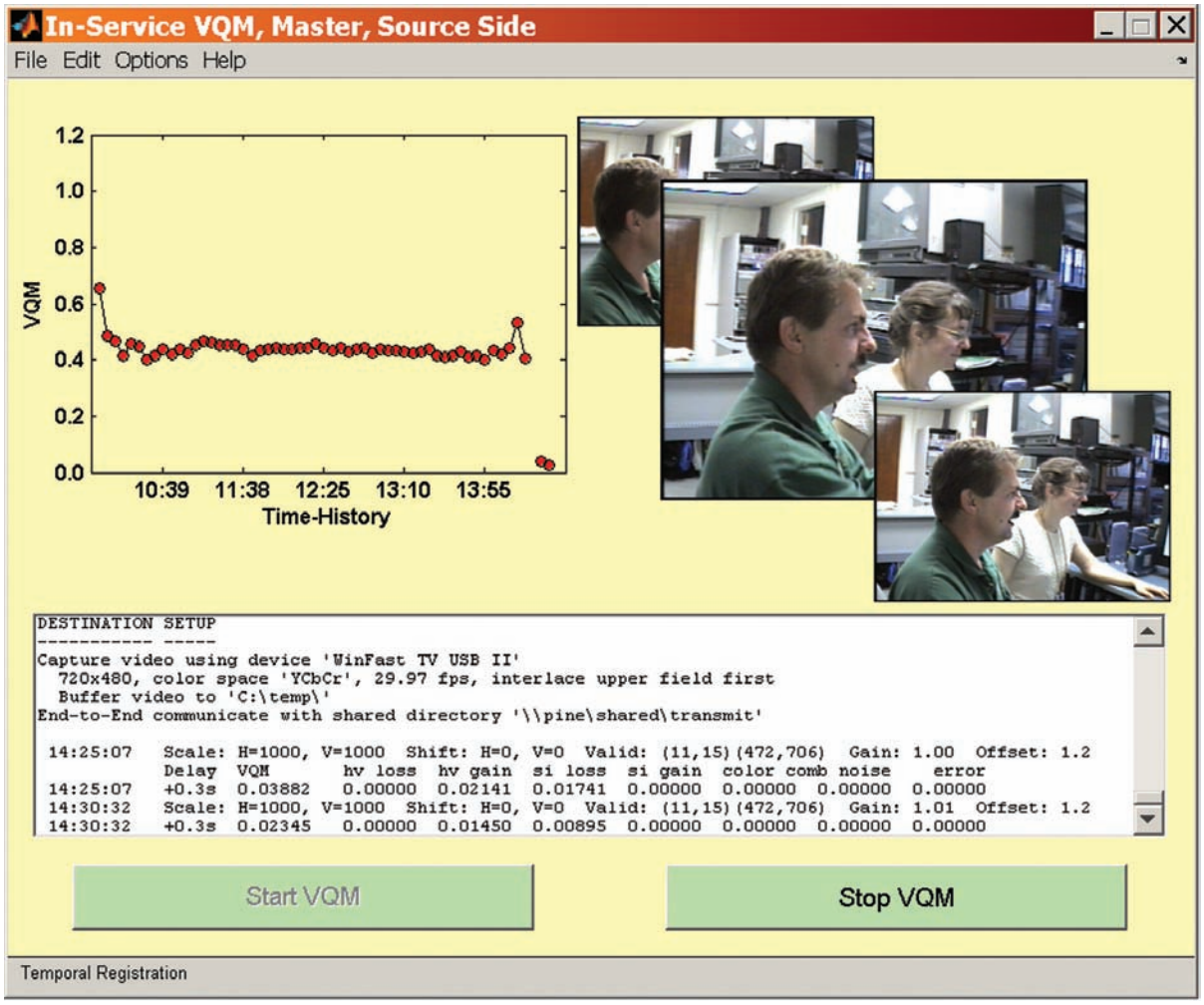
Objective metrics for quantifying the performance of digital video systems (e.g., direct broadcast satellite, digital television, high definition television, video teleconferencing, telemedicine, internet and cell phone video) are required by end-users and service providers for specification of system performance, comparison of competing service offerings, network maintenance, and use optimization of limited network resources. The goal of the ITS Video Quality Research project is to develop the required technology for assessing the performance of these new digital video systems and to actively transfer this technology to other government agencies, end users, standards bodies, and the telecommunications industry, thereby producing increases in quality of service that benefit all end users and service providers.

To be accurate, digital video quality measurements must be based on perceived "picture quality" and must be made in service. This is because the performance of digital video systems is variable and depends upon the dynamic characteristics of both the input video and the digital transmission system. To solve this problem, ITS has continued to develop new measurement paradigms based upon extraction and comparison of low-bandwidth, perception-based features that can be easily communicated across the telecommunications network. These new measurement paradigms (now commonly known throughout the world as "reduced reference" measurements) have received three U.S. patents, been adopted as the North American Standard for measuring digital video quality (ANSI T1.801.03-2003), been included in two International Telecommunication Union Recommendations (ITU-T Recommendation J.144Revised, ITU-R Recommendation BT.1683), and are currently being used by hundreds of individuals and organizations worldwide.

To facilitate the transfer of ITS-developed video quality metrics (VQMs) into the private sector, ITS has developed two software tools. The first tool, called the "Laboratory VQM Tool," is useful for bench testing of video systems. For this tool, video from the source and destination ends of a video system must be present at a single personal computer (PC). Work was completed in FY 2005 to expand the existing VQM software tools to include new end-to-end video quality monitoring capabilities. This new software tool, called the "In-Service VQM (IVQM) Tool," runs on two PCs, one located at the source end and the other located at the destination end. The two PCs communicate their reduced reference features via the Internet. Using these new software tools, users and service providers can quantify the digital video quality of their networks using methods standardized by ANSI and the ITU.

The figure on the next page gives a screen snapshot of the IVQM monitoring screen (master controlling computer at video source). The IVQM monitoring screen contains a menu bar, a time history plot of the selected VQM, three sample frames from the last video capture (first, middle, and last), a text box listing detailed calibration and VQM results, two buttons ("Start VQM" and "Stop VQM"), and a status bar at the bottom of the screen. VQM estimates are reported on a scale from zero to one, where zero means that no impairment is visible and one means that the video clip has reached the maximum impairment level. The capture time of the sequences is displayed on the X-axis. Results and captured video sequences can be saved for later analysis.

During FY 2005, 176 new Cooperative Research and Development Agreements (CRADAs) were implemented with U.S. companies/individuals and 111 new Evaluation License Agreements (EVAs) were implemented with foreign companies/individuals. These CRADAs and EVAs provide companies with an easy mechanism for evaluating ITS video quality measurement technology and software before signing commercial licensing agreements. As a result of this arrangement, a leading provider of telecommunication performance measurement equipment and services signed a commercial licensing agreement with ITS in FY 2005.



Snapshot of IVQM monitoring screen (master controlling computer at video source).

Recent Publications

M.H. Pinson and S. Wolf, "In-service video quality metric (IVQM) user's manual," NTIA Handbook HB-05-424, Apr. 2005.

S. Wolf and M.H. Pinson, "Low bandwidth reduced reference video quality monitoring system," in *Proc. of First International Workshop on Video Processing and Quality Metrics for Consumer Electronics*, Scottsdale, Arizona, Jan. 2005.

M.H. Pinson and S. Wolf, "Video scaling estimation technique," NTIA Technical Memorandum TM-05-417, Jan. 2005.

Further information can be found on the Video Quality Research home page at http://www.its.bldrdoc.gov/n3/video.

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SUPPORT TO PRIVATE SECTOR TELECOMMUNICATIONS ACTIVITIES:

Cooperative Research with Industry

Outputs

- Interoperability measurements of Project 25 public safety radios.
- Measurements of ad hoc wireless network performance.
- Measurements of time-based transmitter and receiver performance.
- Measurements of X-band emissions from a newly developed radar.

The Federal Technology Transfer Act of 1986, as amended, allows Federal laboratories to enter into cooperative research agreements with private industry, universities, and other interested parties. The law was passed in order to provide laboratories with clear legal authority to enter into these arrangements and thus encourage technology transfer from Federal laboratories to the private sector. Under this Act, a cooperative research and development agreement (CRADA) can be implemented that protects proprietary information, grants patent rights, and provides for user licenses to corporations, while allowing Government expertise and facilities to be applied to interests in the private sector.

ITS participates in technology transfer and commercialization efforts by fostering cooperative telecommunications research with industry where benefits can directly facilitate U.S. competitiveness and market opportunities. ITS has participated for a number of years in CRADAs with private sector organizations to design, develop, test, and evaluate advanced telecommunication concepts. Research has been conducted under agreements with:

- American Automobile Manufacturers Association
- ARINC
- AudioLogic, Inc.
- Coherent Technologies
- Bell South Enterprises
- Bell Atlantic Mobile Systems
- East Carolina University's Brody School of Medicine
- FirstRF Corporation
- General Electric Company
- GTE Laboratories Inc.
- Hewlett-Packard Company (HP)
- Integrator Corporation
- Intel Corporation
- Lehman Chambers
- Lucent Digital Radio
- Lucent Technologies
- Motorola/Freescale Inc.
- Netrix Corporation
- RF Metrics
- Savi Technologies
- Spectrum Mapping LLC
- Telesis Technology Laboratories
- University of Colorado
- University of Pennsylvania
- US WEST Advanced Technologies
- US WEST New Vector Group

Not only does the private sector partner benefit, but the Institute is able to undertake research in commercially important areas that it would not otherwise be able to do. Active CRADAs in FY 2005 are described below.

The State of Wyoming and ITS cooperated in the testing of the interoperability of Project 25 radio equipment for a statewide public safety wireless network. In support of the State of Wyoming procurement of new public safety radio equipment, ITS worked with the various vendors to test the performance and interoperability of their various radios. This work supported Wyoming's determination of which equipment would best meet the state's public safety communication needs. It also provided results useful to ITS' support of various Federal departments and agencies involved with public safety.

The University of Colorado conducted measurements of the performance of ad hoc wireless networks with both ground-based and airborne terminals at ITS' Table Mountain Field Site. The Table Mountain Field Site is a National Radio Quiet Zone protected by Federal Regulation. Using IEEE 802.11 type equipment, routing protocols were tested and the performance of the ad hoc networks monitored. These measurements are contributing to the development of new wireless ad hoc network technologies.

ITS supported RF Metrics in RF link testing between a Time-Based Transmitter and a Time-Based Receiver at the Table Mountain Field Site. These systems are general purpose, software-controlled radios with a special distinction. The transmitter is capable of adjusting the output waveform in time to 1 nanosecond RMS of an input time

ITS and RF Metrics staff at the Table Mountain field site, preparing to measure the characteristics of the electromagnet emissions from a newly developed X-band radar (photograph by F.H. Sanders).

reference. The receiver is capable of time-stamping the received signal with the same resolution. The purpose of this test was to establish the RF link between the two systems in a real-world environment, and make measurements of the system performance during the communication session.

RF Metrics and ITS also made X-band radar emission measurements at the Table Mountain Field Site. These measurements helped RF Metrics characterize the emissions of a newly designed radar for the manufacturer. ITS benefited by learning how well industry could use the International Telecommunication Union – Radiocommunication Sector Recommendation M.1177 to perform radar emission measurements. ITS was the principal contributor to the Recommendation.

Cooperative research with private industry has helped ITS accomplish its mission to support industry's productivity and competitiveness by providing insight into industry needs. This has led to adjustments in the focus and direction of other Institute programs to improve their effectiveness and value.

ITS is interested in assisting private industry in all areas of telecommunications. The pages of this technical progress report reveal many technological capabilities that may be of value to various private sector organizations. Such organizations are encouraged to contact ITS if they believe that ITS may have technology useful to them. Because of the great commercial importance of many new and emerging telecommunication technologies, including third generation wireless (3G), wireless local area networks, digital broadcasting, and intelligent transportation systems, ITS will continue to vigorously pursue technology transfer to the private sector through CRADAs and thereby contribute to the rapid commercialization of these new technologies. ITS also plans to commit substantial labratory resources to the development and standardization of new telecommunication technologies.

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ITU-R Standards Activities

Outputs

- Technical support to the U.S. Administration in Working Party 8B, the Radar Correspondence Group, and Joint Rapporteurs Group 1A-1C-8B, as well as Study Group 3 (see pp 36-37).
- Measurements to determine aggregate emission characteristics and performance of prototype 5-GHz dynamic frequency selection devices.
- Tests and measurements performed on effects of interference from communication system signals into a maritime radionavigation radar.
- Presentations to the ITU-R Radar Seminar.
- Joint development of a method for measuring radar antenna patterns across broad frequency ranges simultaneously with measurement of radar emission spectra.
- Joint measurements of the effects of transmitter rotary joints on radar emission spectra.

Success in worldwide telecommunication markets, as well as effective and compatible use of telecommunications technologies both domestically and abroad, is critical to the long-term economic health of the United States. To achieve these goals, the U.S. Administration actively participates in the single most important worldwide telecommunications standards and regulatory body, the International Telecommunication Union's Radiocommunication Sector (ITU-R), to further its objectives with regard to all forms of wireless communication on a worldwide basis. ITS in turn provides important, ongoing technical support for the U.S. Administration in ITU-R Study Groups 3 and 8; Working Party (WP) 8B; the Radar Correspondence Group (RCG), and the Joint Rapporteurs Group (JRG) 1A-1C-8B. Current areas of interest include (but are not limited to): potential reallocation of radar spectrum; effects on radars of interference from communication systems; dynamic frequency selection technology proposed for 5-GHz spectrum sharing between communication systems and radars; development of radar emission spectrum measurement techniques; and development of more efficient radar spectrum emissions.

A number of proposals have been made by non-U.S. Administrations in ITU-R to introduce communication systems into bands that have heretofore been allocated for radars on a primary basis. One of these is dynamic frequency selection, in which communication systems automatically sense the presence of radar signals and avoid operations on locally occupied radar frequencies. Another approach that has been suggested is to allow interference from communication systems to radars on some sort of statistical basis.

Since the U.S. Administration has made an enormous investment in the development and deployment of both military and civilian radars, it is essential that new systems proposed for spectrum sharing with radars be shown to be electromagnetically compatible with existing and future radars. To this end, in FY 2005 ITS engineers tested the new technology, called dynamic frequency selection (DFS), for the U.S. Administration. The tests were conducted jointly by ITS, the NTIA Office of Spectrum

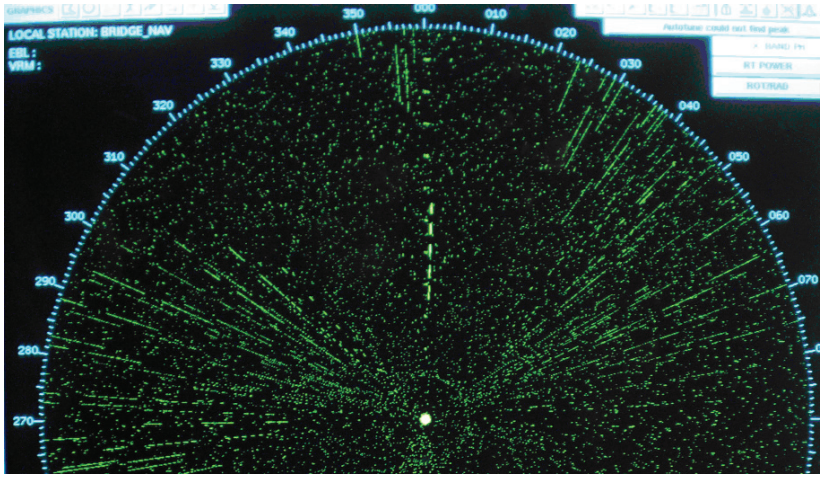

Figure 1. Interference effects in a radar receiver during ITS testing in support of the US Adminstration in ITU-R. Photo by F.H. Sanders.

Management (OSM), other Federal agencies, and industry. Several 5-GHz DFS RLAN prototypes were tested at the ITS Boulder laboratory to determine the extent to which they could successfully sense the presence of radar signals; those results were used by the U.S. Administration at ITU-R meetings in FY 2005.

Figure 2. The 2005 ITU-R Radar Seminar in progress (photograph by F.H. Sanders).

Regarding the statistically-allowed interference technique, ITS and OSM have worked together for several years to study the effects of interference in radar receivers. In FY 2005, interference tests and measurements were performed by ITS and OSM engineers on a maritime radionavigation radar at a Coast Guard site. Interference signals were injected into the radar receiver while targets were observed. At a variety of interference levels, the effects on target detection were observed. The effects of swept-frequency pulses generated by some other radars, called chirped pulses, were also studied. The radar receiver was found to be highly sensitive and susceptible to interference from communication signals at low levels, well below the noise floor of the radar. However, no interference effects were noted in the presence of chirped pulses and other types of radar pulses; these results indicated that the radionavigation radar was highly compatible with other radar systems but not so compatible with communication signals. The test results have been used for U.S. Contributions in WP 8B.

An ITS engineer chairs the Radar Correspondence Group, and ITS provides ongoing support and written Contributions for JRG 1A-1C-8B on future development of radar technology in the X band (9300-9500 MHz). Using data gathered from radar emission measurements at the ITS Table Mountain facility, two ITU-R Contributions were written, calling for changes in the current ITU-R procedures for measurements of radar spectra. In yet another Contribution, a new method for simultaneous measurement of radar emission spectra and antenna patterns across broad frequency ranges was described, again based on data taken at the Table Mountain facility.

ITS and OSM engineers wrote two presentations for the U.S. Administration that were given to the ITU-R as part of its 2005 Radar Seminar. The presentations summarized the results of U.S. studies on DFS, and the results to date of U.S. radar interference studies.

Finally, in FY 2005 ITS organized and hosted an important meeting of Study Group 3 in Cleveland, Ohio, on propagation studies and issues.

Recent Publications

F.H. Sanders, R. Hinkle, and B. Ramsey, "Measurement procedures for the radar spectrum engineering criteria (RSEC)," NTIA Report TR-05-420, Mar. 2005.

F.H. Sanders, "Bandwidth dependence of emission spectra of selected pulsed-CW radars," NTIA Technical Memorandum TM-05-431, Aug. 2005.

F.H. Sanders and B.J. Ramsey, "Comparison of radar spectra on varying azimuths relative to the base of the antenna rotary joint," NTIA Technical Memorandum TM-05-430, Aug. 2005.

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ITU-T & Related U.S. Standards Development

Outputs

- Leadership of ITU-T and related U.S. telecommunications standards committees.
- Technical contributions presenting U.S. standards proposals and ITS research results.
- Proposed ITU-T Recommendations and associated U.S. industry standards.

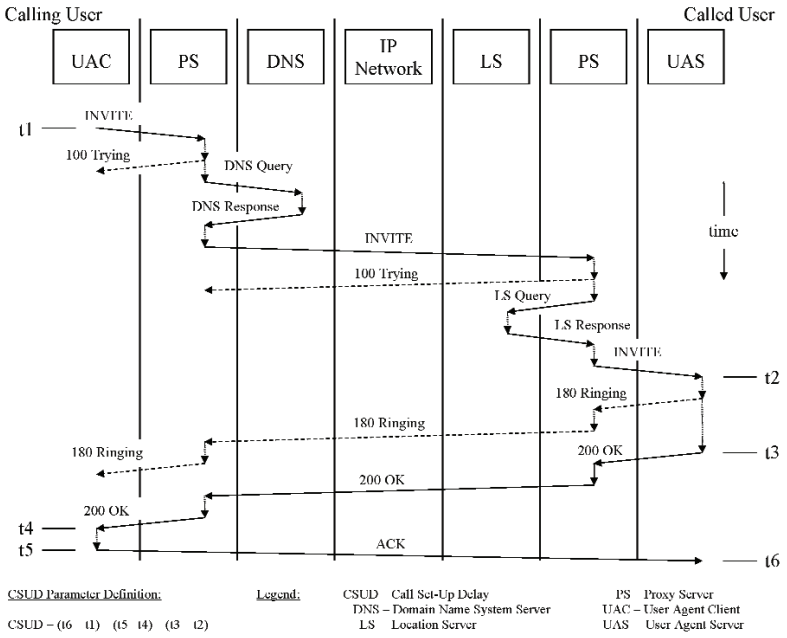
The Institute has a long history of leadership, technical contributions, and advocacy of U.S. Government and industry proposals in the International Telecommunication Union's Telecommunication Standardization Sector (ITU-T) and related U.S. standards organizations. ITU-T is a specialized agency of the UN, responsible for developing the international standards (Recommendations) providers use to plan, interconnect, and operate public telecommunication networks and services worldwide. ITU-T's Recommendations impact both the evolution of U.S. telecommunications infrastructures and the competitiveness of U.S. telecommunications products in international trade.

The Institute's long-term goal in ITU-T (and in related national standards work) is to motivate the standardization of user-oriented, technology-independent measures of telecommunication Quality of Service (QoS) — and to relate those user-oriented measures with the technology-specific performance metrics and mechanisms providers use to provision and operate networks. This ITS work promotes fair competition and technology innovation in the telecommunications industry, facilitates interworking among independently-operated networks and dissimilar technologies, and gives users a quantitative, practical means of defining their telecommunication requirements and selecting products and services that meet them.

In FY 2005, the Institute provided leadership in two key ITU-T groups: Study Group (SG) 13 and SG 9's Working Group on Quality Assessment. SG 13 is developing technical standards that will enable the convergence of circuit-switched and packet-switched networks in Internet Protocol (IP) based Next Generation Networks (NGNs). SG 13 is also responsible for NGN standardization release planning and project management. An ITS staff member serves as Vice Chair of ITU-T SG 13 and its NGN Focus Group (FGNGN), and chairs SG 13's Working Party (WP) 4, which develops technical standards on NGN QoS and Operation, Administration, and Maintenance (OAM). The FGNGN in particular has attracted strong industry support, with international meetings every two months, average attendance exceeding 150, and over 900 technical contributions during FY 2005. SG 9's Working Group on Quality Assessment defines quality objectives for integrated broadband cable networks and television and sound transmission. In that group ITS chairs Question 14/9, "Objective and Subjective Methods for Evaluating Audiovisual Quality in Multimedia Services." ITS also provides leadership and technical contributions in the ITU affiliated Video Quality Experts Group (VQEG) and the Alliance for Telecommunications Industry Solutions (ATIS) Network Performance, Reliability and Quality of Service Committee (PRQC), formerly T1A1. VQEG works in conjunction with ITU-T SG 9 and ITU-R WP 6Q (Broadcasting Services — Performance Assessment and Quality Control) to develop objective, computer implementable, perception-based video quality metrics (VQMs) that emulate the human visual system. PRQC develops national standards and contributes strongly to ITU-T standardization in all of these technology areas. ITS also leads the Joint Rapporteur Group on Multimedia Quality Assessment (JRG-MMQA) a cross-cutting ITU-T standards body that unites the video quality expertise of SG 9 with the audio quality expertise of SG 12 in a cooperative effort to develop objective, perception-based metrics for combined audio and video signals in mobile and PC environments.

Under ITS leadership, SG 13/WP 4 drafted three new ITU-T Recommendations during FY 2005: Y.17fw (MPLS management framework), Y.17ethoam (OAM functions and mechanisms for Ethernet-based networks), and Y.123qos (A QoS control architecture for Ethernet-based IP access networks). WP 4 also completed (and SG 13 approved) a revision to ITU-T Recommendation Y.1711 (Operation and maintenance mechanism for MPLS networks). With other leaders, ITS presented NGN standardization results in two ITU-T workshops (NGN Technical Workshop, ITU-T Workshop on NGN in collaboration with IETF). These

two events attracted over 600 attendees. ITS also contributed strongly to the development and approval of a key FGNGN output, published as ITU-T Q-Series Supplement 51 (Signalling Requirements for IP QoS). This specification will be important in standardizing new signalling technologies capable of fully integrating today's wired telephony, video, wireless, and Internet-based infrastructures and services — and motivating the capital investment needed to deploy them.



Example call processing parameter definition.

In PRQC, ITS leadership contributed to new specifications that define priority levels, security requirements, and performance measurement techniques for IP-based networks. ITS also developed PRQC contributions to ITU-T standards work on NGN QoS metrics, specification and apportionment of NGN QoS values, and the allocation of FGNGN work to ITU-T Study Groups. The Institute spearheaded PRQC's FY 2005 efforts to achieve QoS interoperability among NGNs employing different broadband access technologies (e.g., DSL, IPCablecom, Ethernet, Wi-Fi).

In one FY 2005 contribution to PRQC, ITS defined a comprehensive approach to call processing performance specification in networks that use the Internet Engineering Task Force (IETF) defined Session Initiation Protocol (SIP) in establishing and terminating IP media sessions (or "calls"). Such specifications will be needed to support Service Level Agreements (SLAs) and other requirements in deployed NGNs. The figure above shows how one particular SIP-based call processing parameter ("call set-up delay") can be defined. ITS also proposed (and PRQC standardized) an innovative signal processing technology that promotes accurate speech quality measurement in communication systems with rapidly varying transmission delays. Such delays are common in Voice over IP (VoIP) and IP based multimedia communication services, and it will be important to track them in measuring IP network QoS.

ITS has co-chaired the ITU Video Quality Experts Group since its formation in 1997. VQEG enables video experts from many countries to collaborate in developing and evaluating video quality metrics, and its results strongly impact the standardization of VQMs in both ITU-T and ITU-R. The group works primarily via an e-mail reflector, publicly accessible at http://www.VQEG.org. During FY 2005 the number of participants subscribed to this reflector grew to 450. ITS chaired two physical VQEG meetings in FY 2005.

ITS also contributed to VQEG's upcoming Reduced Reference-No Reference (RR-NR) TV and Multimedia video tests during FY 2005, by helping to finalize the test plans and providing video source material. ITS is spearheading new ITU-T work on multimedia quality assessment through its leadership in VQEG and the JRG-MMQA. The latter group met three times during FY 2005.

Recent Publication

C. Dvorak and N. Seitz, "Signalling and interworking challenges for quality of service in the next-generation network," *Journal of the Communications Network*, April-June 2004.

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A transmitter antenna (foreground) exposes a 5-GHz wireless access system (WAS) device (gray, center) to radar pulses during tests at ITS. An antenna behind the WAS antenna (white, right) monitors and verifies the presence of the radar pulses (photograph by F.H. Sanders).

ITS Tools and Facilities

Advanced Antenna Testbed

The advanced antenna testbed (ATB) is a multi-channel test facility based on ITS digital sampling channel probe technology. The system can simultaneously characterize eight wideband radio channels or antenna elements. The system can be configured for multiple channel recordings at one frequency or at multiple frequencies. When configured at one frequency, orthogonal pseudo noise codes can be transmitted from multiple antenna elements. The table below summarizes the range of permissible values for the ITS channel sounding system, as well as giving an example of a measurement system configured for 2.3 GHz and 10 Mb/s operation.

Configurable Testbed Parameters

Parameter	3G Example	ITS System
Receiver Channels	8	1-8 (expandable to 16)
Carrier Frequency	2.3 GHz	.45 – 6 GHz
Bit Rate	10 Mb/s	.1 – 50 Mb/s
Resolution	100 ns	20 ns – 10 µs
Code Type	Maximal Length	Programmable
Code Length	511 bits	Programmable
Acquisition Mode	Burst	Continuous or Burst
Positioning	GPS/Dead Reckoning	GPS/Dead Reckoning
Transmitters	16	Multiple
Data Processing	Post	Post

The ATB provides common reference sites for evaluating next-generation antenna systems. Data from multiple channels can be used to test the diversity gain resulting from various signal combining algorithms. Digital beam forming and multiple input, multiple output (MIMO) techniques may also be examined by simultaneous digitization of signals from multiple antenna elements. Sites in Boulder and Denver, Colorado, serve as known environments for evaluating 3G components and systems. Alternately, the ATB system may be van-mounted for site mapping studies at any required location.

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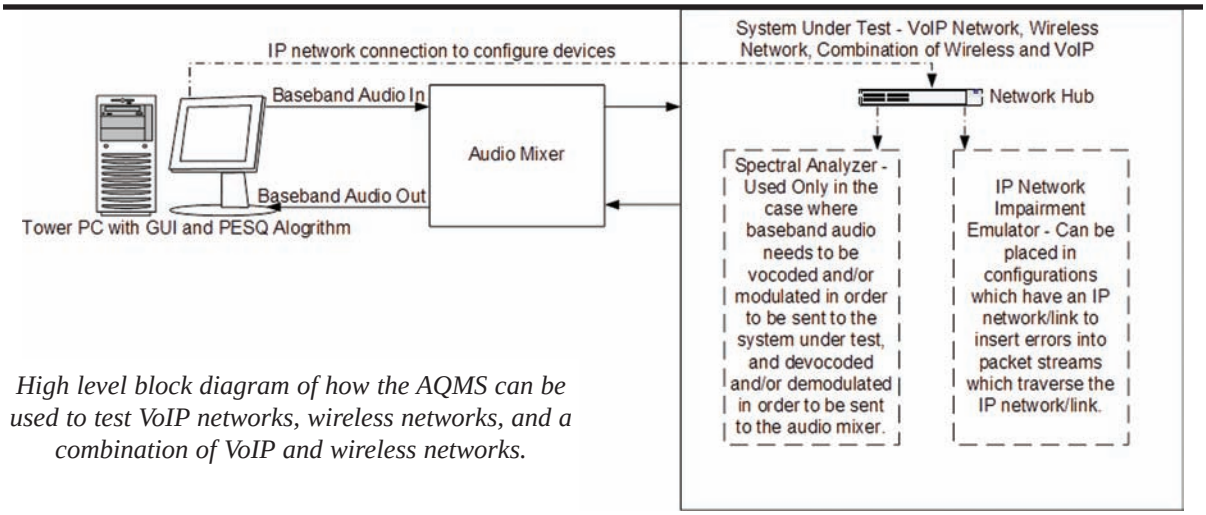
Audio Quality Measurement System (AQMS)

The Audio Quality Measurement System (AQMS) is a tool for evaluating the voice quality of Voice over IP (VoIP) systems, wireless systems, and combination systems consisting of both VoIP and wireless infrastructure. Instead of using an actual panel of individuals to score the audio quality of a particular speech file, an audio quality estimator algorithm, known as PESQ (Perceptual Evaluation of Speech Quality), can be used to provide an estimated mean opinion score (EMOS). The scores are assigned on a scale of 1–5, with 1 being the worst and 5 being the best. The extensive research performed by Stephen Voran in the Audio Quality Research Laboratory acted as a springboard for the development of the AQMS. A block diagram of the AQMS is shown below. The core components of the system are the custom graphical user interface (GUI), the PESQ algorithm, and an audio mixer. The spectral analyzer and the network impairment emulator can be thought of as auxiliary components of the AQMS.



High level block diagram of how the AQMS can be used to test VoIP networks, wireless networks, and a combination of VoIP and wireless networks.

The system works by playing a group of 40 Harvard phonetically balanced speech files into the system under test (SUT). The speech files are started through the GUI. Before playing the speech files into the system, the user can invoke the documentation feature of the GUI interface to record the audio levels of the mixer, the IP impairment levels of the network impairment emulator, the spectrum analyzer's settings, the type of equipment under test, and the configuration of the equipment under test. The GUI also provides the ability to remotely interface to and configure the spectral analyzer and the network emulator before the 40 speech files are played into the SUT. The final feature of the AQMS is that it generates a two-dimensional plot where the x-axis (range is fixed from 1 to 40) represents the speech files and the y-axis represents EMOS. This two-dimensional plot contains other important information such as the median EMOS, average EMOS, the IP impairments selected, and their respective levels.

This system has been used to evaluate the voice quality of a Project 25 VoIP combination system which is comprised of two ultra/very high frequency (UHF/VHF) repeaters which have the capability to transmit over IP links. It has also been used to evaluate the voice quality of VoIP-capable telephones that require the use of session initiated protocol (SIP) or H.323 to make a telephone call.

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Audio-Visual Laboratories

The ITS Audio-Visual Laboratories offer a wide range of audio and video recording, storage, processing, reproduction, objective quality assessment, and subjective testing capabilities. These capabilities in turn support the development and verification of new quality estimation techniques for compressed digital audio and video, the development of novel subjective testing techniques for audio and video signals, and the development of new coding algorithms.

Laboratory equipment supports standard-definition (SD) and high-definition (HD) video signals, as well as monophonic, stereophonic, and 5.1-channel audio streams. Signals are acquired with high-quality microphones and cameras. Recording and playback devices include studio-quality analog and digital video tape recorders with two to eight audio channels, digital audio tape machines, and CD players.

These systems are augmented with several digital audio and video workstations and a set of high quality Analog-to-Digital and Digital-to-Analog converters. Analog audio mixing, filtering, and equalizing equipment is available. An array of digital audio and video encoders and decoders are available as well as an HDTV modulator and demodulators. Analog and digital audio and video routing switchers and patch panels allow for nearly arbitrary interconnections between the various pieces of equipment. Reproduced signals are presented through studio quality video monitors, monitor loudspeakers, headphones, or handsets.

Three separate rooms with controlled visual and/or acoustics environments are available for the subjective testing of audio and video signals. The controlled environments are specified in International Telecommunication Union – Telecommunication Standardization Sector (ITU-T) Recommendation P.800 and International Telecommunication Union – Radiocommunication Sector (ITU-R) Recommendation BT.500 respectively. These specifications address background noise levels, wall colors, light levels, room dimensions, and other properties.

Finally, the labs feature an array of audio and video signal generators and analyzers to support laboratory measurement and calibration activities. Computers play a key role in laboratory operations. Two systems offer the ability to record and play back uncompressed digital audio bit-streams together with synchronized SD video bit-streams that conform to ITU-R Recommendation BT.601 (i.e., Society of Motion Picture and Television Engineers SMPTE 259M/272M specification) and synchronized digital audio streams to and from a high-speed workstation with over 1 TB of hard disk storage. Another computer-based system can record and play back uncompressed HD audio and video bit-streams in accordance with the SMPTE 292M format. Much audio and video processing is performed on a cluster of four high-performance workstations, supported by 12 TB of disk storage.

Lab activities include objective estimation of audio and video quality, and subjective testing of audio and video quality. Random access digital audio video playback systems coupled with discrete-time and continuous-time wired and wireless electronic data entry systems greatly facilitate many of the subjective testing activities. Because multiple subjective testing rooms are available, the laboratory can support conversation, teleconferencing, and

video teleconferencing tests as well as viewing and listening tests. Objective video quality estimation software, written in C++ and MATLAB, processes video signals in accordance with American National Standards Institute (ANSI) T1.801.03-2003, ITU-T Recommendation J.144 Revised, and ITU-R Recommendation BT.1683, resulting in estimates of video quality that show good correlation with subjective test results. Several different objective speech and audio quality estimation algorithms are available, including those defined in ANSI T1.518, ITU-T Recommendation P.862, and ITU-R Recommendation BS.1387. The labs support both batch-mode and real-time objective quality estimation.

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Digital Sampling Channel Probe

The digital sampling channel probe (DSCP), designed and patented at ITS, is used to characterize the wideband propagation characteristics of the radio communication channel. Consisting of a transmitter, receiver, and data acquisition system, the DSCP is used to make complex impulse response measurements. The DSCP digitizes a received pseudo-noise signal at an intermediate frequency (IF) and then post processes the data. The system can collect impulse response data on multiple channels every 600-800 μs. This allows characterization of the Doppler spectrum and time variability of the mobile channel for high frequency systems (up to 5.8 GHz).

Historically, the DSCP has been employed extensively for channel characterization of cellular and personal communications services (PCS). ITS has expanded the probe to 8 channels capable of mobile phased array or multiple input, multiple output (MIMO) measurements. Also available is a wide-bandwidth, high-frequency probe, particularly suited for high resolution requirements such as wireless local area network (LAN) applications up to 30 GHz. For a more detailed description, see http://flattop.its.bldrdoc.gov/rcirms/

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Green Mountain Mesa Field Site

The main Department of Commerce Boulder Laboratories campus contains a field site used for outdoor wireless network research. The site is connected to the ITS laboratories via both fiber optic and 802.11 links. The fiber optic link is currently providing access to the ITS local area network (LAN) while the 802.11 link connects this field site to the ITS Wireless Networks Research Center (see p. 65). The site can provide six independent duplex fiber channels to the ITS lab. This allows research to be conducted over an isolated 1-mile outdoor Wi-Fi link. The fiber connectivity provides a LAN connection to the outdoor wireless router and for capability to operate remote data collection equipment. The outdoor router, located on an 80-foot tower, provides long range 802.11 links to other Commerce field sites. Currently these links provide 802.11b services and are also used for network performance testing.

The site's unique geographic location, several hundred feet above the main Department of Commerce campus, allows for the provisioning of wireless test links over a large portion of eastern Boulder county. The site is operated year round.

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Interoperability Research Laboratory (IRL) and Mobile Radio Communication Performance Measurements

The Interoperability Research Laboratory (IRL) provides ITS with the capability to assess the compliance of land mobile radio (LMR) systems to the Telecommunications Industry Association's TIA-102 and TIA-603 series of standards. Presently this facility is being employed to evaluate LMR standards compliance through tests of radio performance, interoperability and conformance.

The performance measurement capabilities include the usual receiver and transmitter procedures such as receive sensitivity, co-channel and adjacent-channel rejection, spurious response rejection, and transmitter emissions mask. Highly accurate measurements are made possible by laboratory grade signal generators, real-time digital spectrum and vector signal analysis tools, wideband digital oscilloscopes, and other sophisticated measurement equipment. Sensitive measurements are facilitated by the use of a room sized RF shielded enclosure.

Interoperability tests are made possible through interactive testing using the laboratory's extensive cache of Project 25 radios and repeaters, while conformance assessments are accommodated by communications analyzers. The lab possesses both types of commercially available Project 25 compatible communications system analyzers. These instruments can decode various aspects of the link control information, such as network access code, talk group identification, and status bit. Common air interface protocol logging and data capture are supported as well.

The primary use for this capability is compliance assessment of Project 25 LMRs, but the underlying general purpose equipment and facilities can support a much broader range of tests and radio equipment. This capability is available on a first-come, first-served basis by both NTIA and other agencies.

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ITS Internet Services

ITS provides public Internet access to NTIA/ITS publications, program information, meeting information, and online resources such as Telecommunications Analysis Services, which are used by other Federal agencies, research partners, and private industry. Restricted-access services including electronic mail lists are used to facilitate communications with project sponsors and partners, and to support various standards committees. Highlights of ITS Internet Services include:

- Information about ITS programs and projects. Available at http://www.its.bldrdoc.gov/program/
- An ITS organization chart and a complete listing of ITS staff with contact information. Available at http://www.its.bldrdoc.gov/organization.php
- Recent ITS publications including NTIA Reports, Technical Memoranda, and journal articles. Available at http://www.its.bldrdoc.gov/pub/pubs.html
- Radio propagation data. Available at http://www.its.bldrdoc.gov/data/radio_propagation_data/
- Radio propagation software. Available at http://www.its.bldrdoc.gov/software/
- Information about the Table Mountain field site. Available at http://www.its.bldrdoc.gov/table_mountain/
- Telecommunications Analysis Services. Available at http://www.its.bldrdoc.gov/tas/
- Video Quality Metric Software. Available at http://www.its.bldrdoc.gov/n3/video/vqmsoftware.htm
- Information about ITS-sponsored events such as ISART. Available at http://www.its. bldrdoc.gov/meetings/
- The ITS Brochure. Available at http://www.its.bldrdoc.gov/ITS_brochure/ITS_brochure.pdf

ITS home page: http://www.its.bldrdoc.gov

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ITS Local Area Network

ITS maintains a highly flexible local area network to support local networking services and laboratory interconnections. A structured cabling system interconnects all offices and laboratories with optical fiber, category 5, and category 6 twisted-pair cabling to support high-bandwidth communications on demand. Over 200 devices are supported on 10Base-T, 100Base-T, and gigabit segments. This provides ITS with great flexibility and rapid reconfiguration capability for new programmatic needs. A firewall-based VPN capability securely extends the network to authorized personnel anywhere in the world.

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Mobile Radio Propagation Measurement Facilities

ITS maintains a measurement vehicle capable of radio channel characterization over a wide frequency range. The vehicle is equipped with onboard power, a telescoping mast, azimuth and elevation controllers, and global positioning system (GPS) devices with dead-reckoning backup. A suite of measurement equipment is also available for use in this vehicle, including wideband systems for measuring radio channel impulse response from 450 MHz to 30 GHz. Impulse response measurement capability at 30 GHz with 2ns resolution has been enhanced with the addition of a digital wideband recording system. ITS has increased its mobile channel measurement capability with the addition of an 8-channel receiver and an 8-channel 14-bit data acquisition system. Multi-channel synchronous acquisition can be used for antenna array measurements or multi-frequency broadband measurements. Mobile measurement capability allows space division multiple access (SDMA) algorithms to be studied using data collected in typical mobile environments. This data can then be used to simulate and model radio systems. A suite of measurement software is maintained for calculating mobile propagation metrics from the impulse response data. Typical metrics are power delay profiles, delay spread, received power versus bandwidth, Doppler spectrum and coherence bandwidth.

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Pulsed CW Radar Target Generator

The Pulsed Continuous Wave (CW) Radar Target Generator is an electronic tool used to produce targets on a radar screen. The generator produces signals that simulate the returns that would normally be seen by a radar from targets in the environment. The signals are injected into the radar's receiver at the normal frequency of operation. Several parameters of the signals can be adjusted over a wide range to be compatible with several different radar models. For the same model radar, the number of targets and the range to the targets can be adjusted. Other adjustments include the displayed bearing of the targets and whether the targets are stationary or moving along concentric circular paths. Compensation adjustments can be made for radars that have large tolerances in their operating specifications. The targets can be set to occur at a fixed time interval after a timing pulse (for example, beginning of scan) supplied by the radar. The generator can be used to verify operation or troubleshoot the radar under test. ITS uses the generator to provide simulated desired signals in interference studies where interference is injected into the radar and the effect on the targets is recorded.

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Radio Noise Measurement System

The ITS radio noise measurement system hardware consists of an omnidirectional antenna mounted on a ground plane, preselector filter, low noise preamplifier, off-the-shelf spectrum analyzer, digitizer, and computer. Noise samples are digitized prior to spectrum analyzer detection, just after spectrum analyzer log amplification. Spectrum analyzer demodulation circuits are used for aural noise identification during measurements. The measurement system noise figure is nominally 2 dB above the theoretical noise floor. Noise is measurable approximately 15 dB below and 60 dB above system noise.

The noise measurement system uses custom data acquisition software written and maintained at ITS. The software graphical user interface allows the user to customize and notate each measurement. It also displays noise samples and their corresponding first-order statistics. The statistics are revealed through an amplitude probability distribution (APD). The APD is plotted on a Rayleigh graph where the Gaussian noise appears as a straight line with a negative slope. Non-Gaussian noise is easily identified during measurements as a deviation from the straight line or a change in slope. Non-Gaussian noise exists throughout the radio spectrum.

ITS has used the noise measurement system to measure noise at 137.5 MHz, 402.5 MHz, and 761.0 MHz. The system can also be used to measure noise at higher frequencies, e.g., at 2.4 GHz in spectrum occupied by unlicensed Part 15 low power communication devices such as wireless local area networks and Part 18 industrial, scientific, and medical (ISM) devices such as microwave ovens.

The noise measurement system can be run from a building or a measurement van. A direct current converter with noise suppressor is used to power the van-mounted equipment if 120 V alternating current is not available. Calibration measurements in radio quiet zones have shown that noise contributed by the noise measurement system and power conversion equipment is negligible.

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Radio Spectrum Measurement Science (RSMS) System Tools

The Radio Spectrum Measurement Science (RSMS) system is a state-of-the-art measurement system designed for gathering information regarding spectrum occupancy, equipment compliance, electromagnetic compatibility, and interference resolution. Its purpose is to provide NTIA's Office of Spectrum Management (OSM) with critical measurement support from ITS for determining policies regarding government radio systems and spectrum utilization. The RSMS system is a dynamic and flexible system that incorporates automated, semi-automated, and manual techniques for the measurement and analysis of radio emissions. While not defined by any single hardware configuration, the system includes such devices as the latest in spectrum analyzers, digital oscilloscopes, vector signal analyzers, and signal intercept and collection systems. Measurements can take place in a laboratory or in the field, and they can be mobile or stationary; therefore the system has been made flexible enough to accommodate each of these situations.

An integral part of the system is the measurement vehicle, now in its 4th generation. The vehicle has a highly shielded enclosure (60 dB) with three equipment racks, three 10 meter masts, and a 20 kWatt diesel generator, as well as internet connections, fiberoptic control lines, multiple power outlets, and overhead cable racks. The control and acquisition software is fully developed by ITS so that new and innovative measurement techniques can be easily altered to meet immediate needs. Major objectives in the development of the 4G software have been to provide a tool that can easily accommodate new equipment and different hardware configurations, and to expand on existing measurement capabilities.

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SIPRNET Capability

ITS maintains a connection to the Secret Internet Protocol Routable Network (SIPRNET). This connection allows ITS sponsors and Department of Defense users direct access to ITS tools and facilities in a secure environment, improving the quality of support that the Institute can give organizations with classified needs. Since many of the planning and associated support activities of the military require a classified channel for discussions and data transfer, the need exists for a secure environment within which project planning and support can be carried on without interruption. ITS maintains several computer systems with a variety of software capabilities to support propagation planning and modeling, as well as emerging technologies research. The secure facilities allow users to import data from many military facilities and support organizations into propagation models and other management software. A complete end-to-end propagation planning capability in a secure environment is available for classified needs. Various research studies that ITS conducts (that are determined as classified information) can also reside on the SIPRNET, allowing access by agencies on a need to know basis.

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Spectrum Compatibility Test and Measurement Sets

The introduction of new radio technologies in close physical and frequency proximity to older ones often results in electromagnetic compatibility (EMC) problems. Although theoretical models and simulations provide useful information in guiding design decisions, the complexity of modern systems and the existing spectral environment often require real-world measurements of a proposed system's effects within its proposed operating environment to determine its impact on other users of the radio spectrum. Another problem is to adequately produce controlled interfering signals with known characteristics in environments where suspected interferers may be

unavailable for tests and measurements, e.g., laboratory investigations of possible interference from ship or aircraft mounted radars or communications systems. In both situations a system is needed that simulates the spectral emissions of other devices with a wide range of latitude. An example is the requirement to determine the thresholds at which various types of interference from communication transmitters are manifested as observable interference effects in a variety of radar receivers. Another example is to determine the ability of dynamic frequency selection (DFS) wireless communication devices to detect various types of radar energy without actually obtaining a wide variety of real radars for tests.

To meet these needs, ITS engineers have developed two different approaches to generating interference signals. One approach is to build custom hardware and software combinations of discrete-component equipment, including programmable arbitrary waveform generators, mixers, RF signal generators and amplifiers. ITS uses a number of these configurations to simulate the spectral output of a wide variety of communication systems. These signals can be coupled directly into a system under test or they can be transmitted through space into a target system's receiver to more accurately gauge its response to a real interference situation. The second approach is to utilize high-speed digitizers, called vector signal analyzers (VSAs) to record interference waveforms in bandwidths up to 36 MHz, and to then radiate (or hardline-couple) those waveforms into victim receivers using vector signal generators (VSGs) that operate somewhat as inverses to VSAs. Alternatively, VSGs may be preprogrammed with mathematical information to create particular types of modulation, such as quadrature phase shift keyed (QPSK) signals. The ITS VSGs can be used in conjunction with high-power amplifiers to generate interference signals at high power at frequencies as high as 26 GHz. The advantages of VSGs include simplicity of operation and use, plus the ability to replicate very complex interference waveforms with complete confidence in the fidelity of the simulated signal to the characteristics of the original signal from which it was derived.

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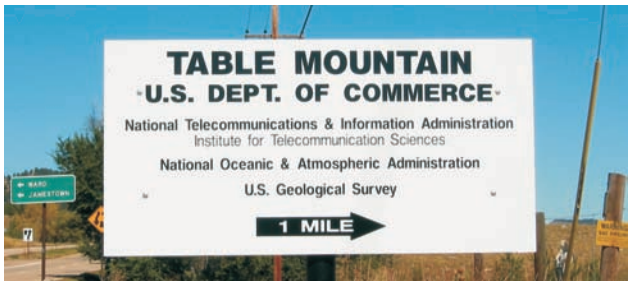

Table Mountain sign on US 36 (photo by J.D. Ewan).

Table Mountain Field Site and Radio Quiet Zone

Established in 1954, the Table Mountain Field Site and Radio Quiet Zone is a unique radio research facility. Located north of Boulder, the site extends approximately 2.5 miles north-south by 1.5 miles east-west, and has an area of approximately 1,800 acres. The site is designated as a Radio Quiet Zone where the magnitude of strong, external signals is restricted by State law and Federal Regulation to minimize radio-frequency interference to sensitive research projects. Facilities at the Table Mountain site include:

- **Spectrum Research Laboratory** — A state-of-the-art facility for research into radio spectrum usage and occupancy. Radio Quiet restrictions ensure that no signal incident on the mesa overpowers any other.
- **Open Field Radio Test Site** — A flat-topped butte with uniform 2% slope, Table Mountain is uniquely suited for radio experiments. It has no perimeter obstructions and the ground is relatively homogeneous. This facilitates studying outdoor radiation patterns from bare antennas or antennas mounted on structures.
- **Mobile Test Vehicles** — There are several mobile test equipment platforms available at the mesa, ranging from 4-wheel drive trucks to full-featured mobile laboratories.
- **Large Turntable** — A 10.4-meter (34-foot) diameter rotatable steel table mounted flush with the ground. Laboratory space underneath houses test instrumentation as well as the control equipment and motors to rotate the turntable. This facility can be operated remotely by computer.
- **18.3 Meter (60 Foot) Parabolic Dish Antennas** — These two antennas are steerable in both azimuth and elevation and have been used at frequencies from 400 MHz to 6 GHz.

- **Radar Test Range** — A large space just south of the Spectrum Research Laboratory is available for testing radar systems.

The Table Mountain Research program supports a number of research activities, e.g., studying the effects of radio propagation on the integrity of digital signal transmission and video quality, environmental and man-made noise, verification of antenna propagation models, and the development of measurement methods needed to assess efficient spectrum occupancy and usage (see pp. 10-11). Partnerships and cooperative research activities are encouraged at the site. Other organizations currently using the facilities include the National Oceanic and Atmospheric Administration (NOAA), the U.S. Geological Survey (USGS), and the Deep Space Exploration Society.

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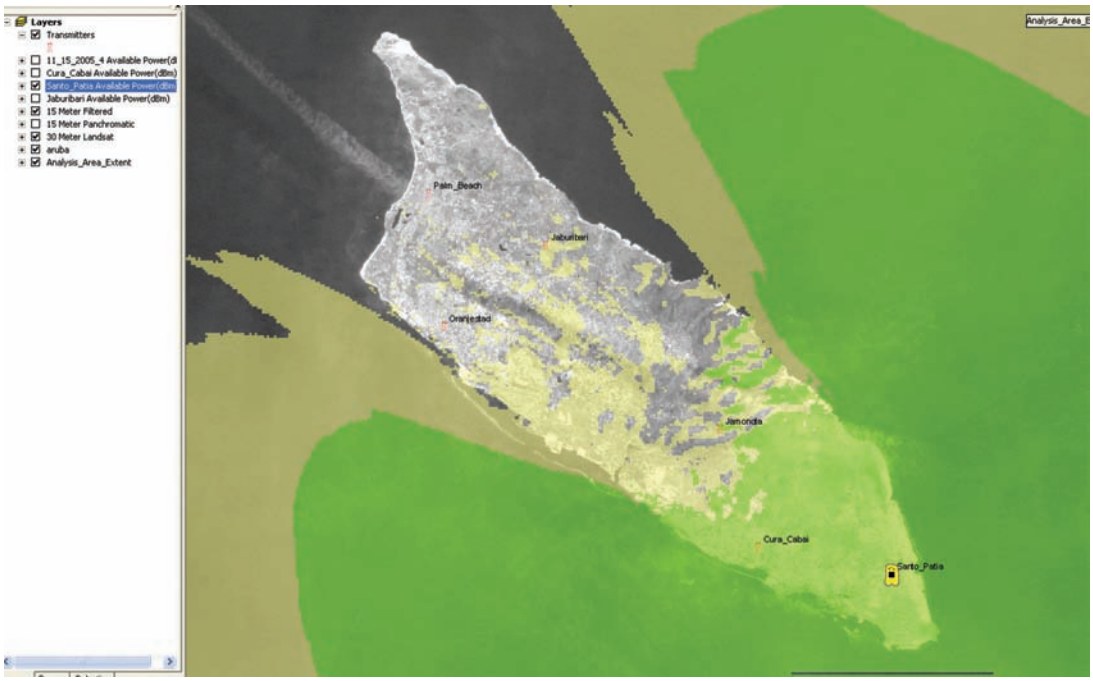
Telecommunications Analysis Services

The Telecommunications Analysis Services (TA Services) program provides the latest engineering models and research data developed by ITS to industry and other Government Agencies via a web-based interface (http://flattop.its.bldrdoc.gov). Designed to be both user-friendly and efficient, it offers a broad range of programs that allow the user to design or analyze the performance of telecommunications systems. Currently available are: on-line terrain data with 1-arc-second (30 m) resolution for CONUS and 3-arc-second (90 m) resolution for much of the world, and GLOBE (Global Land One-km Base Elevation) data for the entire world; 2000 census data, 1990 census data (also 1997 updated); Federal Communications Commission (FCC) databases; and geographic information systems (GIS) databases (ArcInfo). TA Services has developed models that predict communication system coverage and interference for many broadcast applications. New models in the GIS environment for personal communications services (PCS) and Local Multipoint Distribution Services (LMDS) have been developed (see pp. 32-33). The TA Services computer has 210 GB of storage capacity. The following is a brief description of programs available through TA Services.

HAAT – Calculates Height Above Average Terrain for an antenna at a specified location.
PCS/LMDS – Allows the user to create or import surfaces which may include terrain, buildings, vegetation, and other obstructions in order to perform line of sight (LOS) and diffraction studies.
FCCFIND, FMFIND, TVFIND, AMFIND, and TOWERFIND – Allows the user to search the FCC database for particular stations or by search radius around a point of interest.
PROFILE – Extracts path profiles according to user-specified input parameters. After the data is extracted, either the individual elevations or an average elevation along the profile can be obtained. A user can also receive plots of the profiles adjusted for various K factors. For microwave links, Fresnel zone clearance can be determined so that poor paths can be eliminated from a planned circuit or network.
SHADOW – Plots the radio LOS regions around a specified location in the United States using digitized topographic data. The program shows areas that are LOS to the base of the antenna, areas that are LOS to the top of the antenna, and areas that are beyond LOS to the antenna.
TERRAIN – Plots terrain elevation contours from any of the terrain databases available (1-arc-second SDTS for CONUS, 3-arc-second USGS, and GLOBE for the whole world).
COVERAGE – Calculates the received signal levels along radials that are spaced at user-defined intervals of bearing around the transmitter. The program lists the contours of signal coverage of the transmitter along each radial and lists distances to user-specified contours for each radial. Either the FCC broadcast rules or the ITS Irregular Terrain Model (ITM) can be chosen for calculations.
CSPM – Determines the system performance of mobile and broadcast systems in detailed output plots of signal intensity. Plotted outputs can be faxed to the user, plotted on clear plastic for overlaying on geopolitical maps, or downloaded to the user site (in HPGL, GIF, or TARGA format). This program uses the ITS ITM in a point-to-point mode, or other user-chosen algorithms for path loss calculation.
HDTV – Allows the user to analyze interference scenarios for proposed digital television (DTV) stations. The model contains current FCC and MSTV allotment tables and maintains the catalogs created by all program users. The user can create new stations by hand, or by importing station information directly from the FCC database. Analyses may be performed using existing FCC database and allotment assignments, or the user can replace a station with one created and maintained in his/her catalog.
NWS – A specialized application to assist the National Weather Service in maintaining its catalog of weather radio stations (currently about 920).
PBS – An analysis model similar to the HDTV model, but specialized for Public Broadcasting



Coverage study of Santo Patia (Aruba).

Stations (PBS). Typical outputs may consist of composite plots showing Grade A and B coverage of several stations or "overlap" plots which show areas covered by more than one station.

ICEPAC/VOACAP/REC533 – High Frequency prediction models which can be downloaded (free) and executed on Windows based platforms.

ITM – Source code available for the ITS Irregular Terrain Model (Longley/Rice).

IF-77 – Source code available for the IF-77 Air/Ground, Air/Air, Ground/Satellite prediction software (.1 to 20 GHz).

Contact: Robert O. DeBolt (303) 497-5324
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Wireless Networks Research Center (WNRC)

The Wireless Networks Research Center (WNRC) provides a common laboratory area for research in the areas of wireless networks and wireless network access technologies. The WNRC allows the Institute to consolidate efforts in several areas, such as the RF/network interface. This work uses RF link characterization correlated with low-level network management protocols to develop PCS-to-PCS interference models, wireless network propagation models, non-cooperative wireless measurement, and wireless network discovery. RF/network interface measurement devices are used to make detailed measurements of PCS and cellular networks. One device uses a series of PCS/cellular phones to extract low-level protocol messages, network management information, and RF signal quality parameters. Another device has the ability to perform provider-independent PN offset scans and cdma2000 level 3 message logging.

The WNRC contains an experimental IEEE 802.11b wireless local area network (WLAN). ITS has conducted a series of wireless Voice over IP (VoIP) tests utilizing this infrastructure. The WLAN resources include IP packet logging equipment that can be used in network measurements. A code domain analyzer (CDA) measurement capability, used to collect both short and long term Walsh channel data for any target IS-95 base station, has been added to the WNRC. The CDA operates in both the cellular and PCS frequency bands and can be used in fixed or mobile environments. The WNRC is used to conduct ITS work in the area of inter-PCS interference, in support of the Alliance for Telecommunications Industry Solutions (ATIS) subcommittee WTSC/G3GRA. ITS also has the capability to simulate PCS interference using a series of ITS implemented interference models.

Contact: Christopher J. Behm (303) 497-3640
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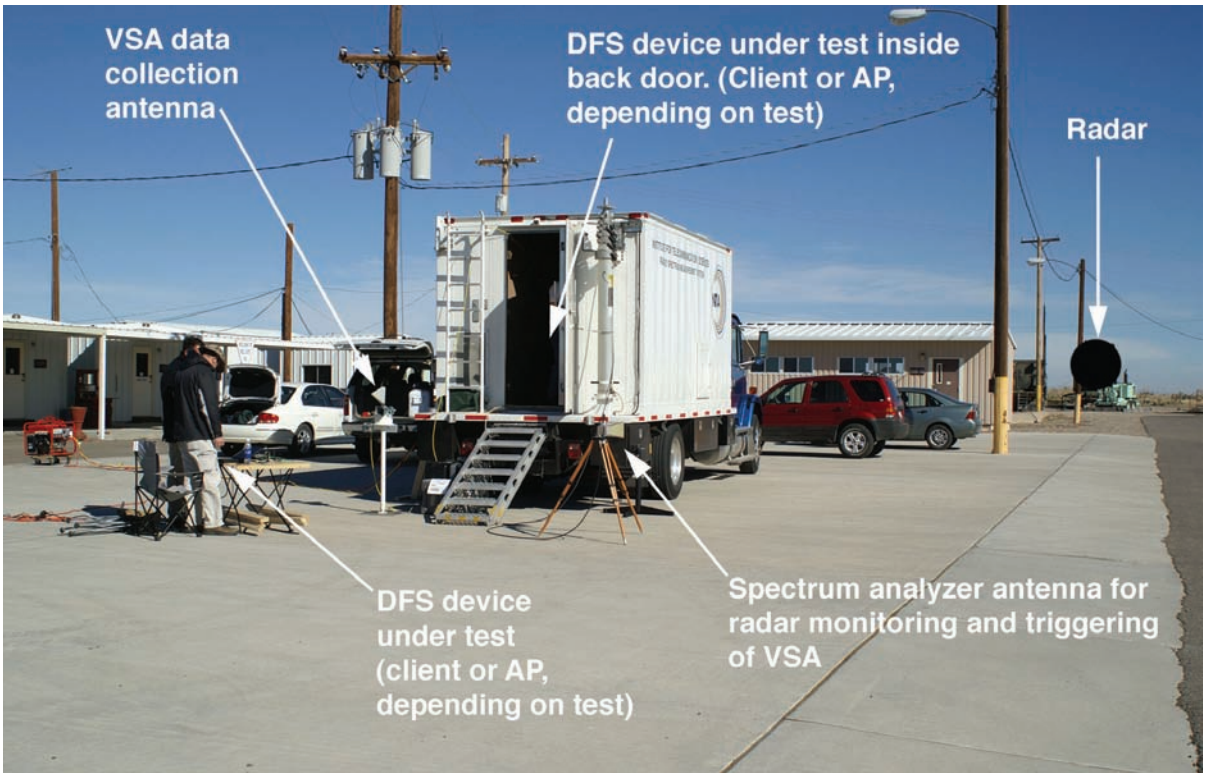


ITS and OSM engineers monitor test and measurement equipment during field testing of a prototype 5 GHz dynamic frequency selection (DFS) RLAN device at a field site in the American southwest. Annotations indicate the configuration of the test hardware (photograph by F.H. Sanders).

An ITS engineer checks the performance of measurement equipment during radar interference tests at the Curtis Bay Coast Guard station near Baltimore, MD (photograph by F.H. Sanders).

ITS Projects in FY 2005

NTIA Projects

Audio Quality Research
Identify and contribute to selected open questions in the areas of digital speech and audio compression, transmission, and quality assessment. Investigate quality assessment and robust speech coding questions related to the deployment of VoIP systems. Deliverables include technical publications and presentations, algorithms, software, and laboratory demonstrations as requested.
Project Leader: Stephen D. Voran (303) 497-3839
e-mail svoran@its.bldrdoc.gov

Broadband Wireless Research
Continue development of state-of-the-art measurement systems for collecting broadband radio-wave propagation data. Provide measurement tools and propagation data used for simulation of the spectral efficiency of proposed communication systems. Deliverables include publications.
Project Leader: Peter B. Papazian (303) 497-5369
e-mail ppapazian@its.bldrdoc.gov

Broadband Wireless Standards
Develop technical means to improve predictions of signal coverage and interference for 3G wireless services through support to ITU-R, TIA TR-8 (Project 25), and other organizations. Building on previous ITS work, develop propagation model comparisons, apply the models to data sets, determine differences during comparison, document results, and start enhancement to ITM of effective antenna height. Deliverables include model enhancements, and standards contributions and leadership.
Project Leader: Paul M. McKenna (303) 497-3474
e-mail pmckenna@its.bldrdoc.gov

Electromagnetic Compatibility Research Support
Advance research in electromagnetic compatibility issues with the technical subcommittee of the Interdepartment Radio Advisory Committee; the US Working Party 8B of ITU-R; and the U.S. Administration in ITU-R Study Group 8 and ITU-R Working Party 8B. Provide technical inputs in the form of NTIA Reports; ITU Contributions; presentations at national and international meetings; and participation in national and international meetings.
Project Leader: Frank H. Sanders (303) 497-7600
e-mail fsanders@its.bldrdoc.gov

Interference Protection Criteria
Provide analysis and measurement results pertaining to the effects of selected types of interference into selected receiver types, and set the stage for additional work. Outputs include written documents that describe the results of interference measurements on radar receivers, and a method for moving forward with this work in subsequent years.
Project Leader: Frank H. Sanders (303) 497-7600
e-mail fsanders@its.bldrdoc.gov

RCG/JRG-1A/8B Website Support
Support the U.S. Administration in ITU-R activities by maintaining the U.S. website for the WP 8B Radar Correspondence Group and Joint Rapporteurs Group 1A/8B.
Project Leader: Jeanne M. Ratzloff (303) 497-3330
e-mail jratzloff@its.bldrdoc.gov

Network Interoperability
Derive and use a systems engineering-oriented framework to understand, and address, the integral components/elements of interoperability and their associated technical issues; analyze real world interoperability issues in the laboratory and use the results to ensure the utility of the framework. Deliverables include contributions to Project 25/ TR-8 meetings.
Project Leader: Jeffrey R. Bratcher (303) 497-4610
e-mail jbratcher@its.bldrdoc.gov

Network Performance
Provide objective, expert leadership and key technical contributions in ITU T and related U.S. industry committees responsible for developing broadband network performance, Quality of Service (QoS), Operation, Administration and Maintenance (OAM), and resource management standards.
Project Leader: Neal B. Seitz (303) 497-3106
e-mail nseitz@its.bldrdoc.gov

Networking Technology
Characterize and analyze the fundamental aspects of networks and network interoperability. Continue the development of networking technology methodologies and tools to address network management and network security/protection issues. Deliverables include a report, software, and a user manual.
Project Leader: David J. Atkinson (303) 497-5281
e-mail dj@its.bldrdoc.gov

Noise Analysis, Measurements, and Modeling
Perform initial work in the development of new knowledge and models for understanding noise in the radio spectrum, and set the stage for additional work. Outputs include documents describing current literature in this field, a set of proposed methods for moving forward with noise assessment measurements, and a set of example measurements of noise in selected radio environments.
Project Leader: Michael G. Cotton (303) 497-7346
e-mail mcotton@its.bldrdoc.gov

Spectrum Engineering Support
Study the factors related to replacing current federal single-agency LMR systems with a Federal shared radio system in the Washington, DC area. Perform measurements as needed to determine radio spectrum usage in the United States, to ensure compliance of new devices with existing regulations, and to resolve interference problems in cases where a Government radio system may be involved as a victim or interferer. Provide reports as appropriate.
Project Leader: Robert J. Matheson (303) 497-3293
e-mail rmatheson@its.bldrdoc.gov

Policy Support
Provide engineering and technical support to NTIA in telecommunications policy development. Provide support on various near-term issues, including broadband wireless access, 3rd generation wireless systems, privacy issues, information technology advances, and critical informal protection.
Project Leader: Alan W. Vincent (303) 497-3500
e-mail avincent@its.bldrdoc.gov

RSMS Enhancements
Develop and maintain software, hardware, systems, and equipment to meet the immediate needs of FY 2005 operations tasks. Implement enhancements to the current stepped measurement capabilities. Develop signal sinulation capabilities.
Project Leader: J. Randy Hoffman (303) 497-3582
e-mail rhoffman@its.bldrdoc.gov

RSMS 4th Generation Development
Provide new and innovative measurement tools for current and future Radio Spectrum Measurement Science (RSMS) capabilities. Continue to develop and document the architectural design of the core software. Add additional instrument modules to the collection of Dynamic Link Libraries (DLLs).
Project Leader: J. Randy Hoffman (303) 497-3582
e-mail rhoffman@its.bldrdoc.gov

RSMS Operations
Provide NTIA with critical measurement support to determine radio spectrum usage across the U.S.; resolve interference problems involving Government radio systems; and determine the emission characteristics of radio transmitter systems that may affect Government operations.
Project Leader: J. Randy Hoffman (303) 497-3582
e-mail rhoffman@its.bldrdoc.gov

Table Mountain Modernization
Ensure a safe working environment at the Table Mountain field site, maintain and upgrade the site infrastructure, and provide support for research activities ongoing at ITS.
Project Leader: J. Wayde Allen (303) 497-5871
e-mail wallen@its.bldrdoc.gov

Table Mountain Research
Utilize the Table Mountain field site and radio quiet zone to support fundamental research into the nature, interaction, and evaluation of telecommunication devices, systems, and services. Actively solicit research proposals that will expand the institute's knowledge base, help identify emerging technologies, and develop new measurement methods to study the characteristics of new devices and systems.
Project Leader: J. Wayde Allen (303) 497-5871
e-mail wallen@its.bldrdoc.gov

Third Generation Wireless
Develop error models that accurately characterize the mobile radio link and estimate the effect of the radio channel on fundamental wireless network performance parameters, e.g., throughput, delay, and loss, to be used by both industry and Government. Deliverables include reports and presentations which disseminate the results of tasks to the public.
Project Leader: Robert J. Achatz (303) 497-3498
e-mail rachatz@its.bldrdoc.gov

Third Generation Wireless Interference Modeling and Characterization
Building on previous ITS work, develop interference models for viable PCS technologies, and verify and validate the models using software analysis and hardware measurements. Apply the models in characterizing PCS interference for 3G architectures, and determine practical means of mitigating observed interference effects. Deliverables include contributions to ATIS G3GRA and ITU-R TG-8/1.
Project Leader: Timothy J. Riley (303) 497-5735
e-mail triley@its.bldrdoc.gov

Video Quality Research
Develop technology for assessing the performance of digital video transmission systems. Extend previous work to low bandwidth reduced reference (RR) video quality measurements, including multimedia definition (MD) and high definition (HD) video systems. Actively transfer this technology to other Government agencies, end-users, standards bodies, and the U.S. telecommunications industry. Deliverables include technical publications, algorithms and software, and technical standards contributions.
Project Leader: Stephen Wolf (303) 497-3771
e-mail swolf@its.bldrdoc.gov

Other Agency Projects

Department of Commerce / National Institute of Standards and Technology

OLES Communication Standards
Provide engineering support, scientific analysis, technical liaison, and test design and implementation to allow the identification/development and validation of interoperability standards for the justice/public safety/homeland security community, and other communication system products and services supporting telecommunications and information technology needs. Provide technical assessments and evaluations of existing and emerging commercial products and services that may provide interim solutions for various interoperability scenarios. Deliverables include technical standards contributions, reports, economic impact statements, guidelines, handbooks, white papers, and other products as requested.
Project Leader: Val J. Pietrasiewicz (303) 497-5132
e-mail valp@its.bldrdoc.gov

Department of Commerce / National Oceanic and Atmospheric Administration / NOAA Weather Radio Program Office

NOAA Weather Radio System Performance Study
Determine the strengths and weaknesses of the National Weather Service's nationwide radio system, to form a basis for further deployment and enhancement. Provide data that characterizes present transmission capabilities, and a comprehensive analysis consisting of field measurements for each mode in the NWR trimode system (voice, alarm tone and SAME). Advise NWS of the performance metrics which can or should be used to evaluate each mode, and provide documentation of the specific measurement methods used.
Project Leader: Christopher J. Behm (303) 497-3640
e-mail cbehm@its.bldrdoc.gov

Department of Defense

Enhancements to Communication System Planning Tool (CSPT) for DOD
Enhance the ITS CSPT model by upgrading the tool to state-of-the-art GIS systems, and beginning the development of an indoor/indoor-outdoor propagation model.
Project Leader: Robert O. DeBolt (303) 497-5324
e-mail rdebolt@its.bldrdoc.gov

International Symposium on Advanced Radio Technologies (ISART)
Develop and conduct the symposium that addresses emerging, advanced wireless technologies that offer wide application and may affect how the radio spectrum is used. Gather information on these technologies and applications for the sponsor.
Project Leader: J. Wayde Allen (303) 497-5871
e-mail wallen@its.bldrdoc.gov

Department of Homeland Security / National Communications System

Network Reliability and Restoral
Reduce vulnerabilities and enhance restoral capabilities in public telecommunication networks by spearheading the development of network reliability, restoral, and emergency service standards in NRSSC (formerly T1A1.2). Apply computer simulation, reliability analysis, security analysis, and traffic engineering to assist NCS in assessing and optimizing public network reliability, identifying network disruptions, promoting security enhancements, and restoring services, in support of Critical Infrastructure Protection initiatives.
Project Leader: Arthur A. Webster (303) 497-3567
e-mail awebster@its.bldrdoc.gov

Packet Switched Networks
Facilitate the development of Recommendations defining Emergency Telecommunications Service capabilities in ITU-T Study Group 9. Apply computer simulation, laboratory studies, security analyses, and/or traffic engineering to assist NCS in support of PDD-63 and associated Critical Infrastructure Protection initiatives related to broadband cable television networks.
Project Leader: Arthur A. Webster (303) 497-3567
e-mail awebster@its.bldrdoc.gov

Federal Railroad Administration

Railroad Telecommunications Study
Continue technical support to the Federal Railroad Administration as it pertains to railroad telecommunications and the activities of the Association of American Railroads' (AAR) Wireless Communications Task Force (WCTF).
Project Leader: John M. Vanderau (303) 497-3506
e-mail jvanderau@its.bldrdoc.gov

Miscellaneous Federal and Non Federal Agencies

Telecommunications Analysis Services
Develop, maintain, and make available to other Government agencies and to the public, through user friendly computer programs, a large menu of engineering models, scientific and informative databases, and other useful communication tools.
Project Leader: Robert O. DeBolt (303) 497 5324
e-mail rdebolt@its.bldrdoc.gov

U.S. Coast Guard

USCG National Distress and Response System (NDRS) Modernization Project
Provide technical assistance and services to the U.S. Coast Guard as part of its project to modernize and upgrade the current National Distress and Response System (NDRS). Specifically, assist with the Developmental Testing and Evaluation phase of the project, by attending and monitoring the Formal Qualification Test (FQT) and System Integration Test (SIT).
Project Leader: Patricia M. Raush (303) 497-3568
e-mail praush@its.bldrdoc.gov

RTCMSC-117 Marine Radio Measurements
Test marine handheld radios according to a proposed voluntary standard that is under consideration by the Radio Technical Commission for Maritime Services. Determine whether the radios can maintain successful reception in the presence of high-level electromagnetic environments.
Project Leader: Brent L. Bedford (303) 497-5288
e-mail bbedford@its.bldrdoc.gov

Cooperative Research and Development Agreements (CRADAs)

(For more details of the Institute's FY 2005 CRADAs, see pp. 50-51)

Freescale, Inc.

Investigate the interference potential of various UWB waveforms. Generate a range of waveforms representative of existing and proposed UWB systems. Develop measurement procedures and analyses to characterize the interfering UWB signals. Assess UWB interference susceptibility of C-band television receivers. Deliverables include an NTIA Report.

Project Leader: Michael G. Cotton (303) 497-7346
e-mail mcotton@its.bldrdoc.gov

RF Metrics

Make use of the ITS Table Mountain facility to perform measurements of emissions from a manufacturer's new model of X-band radar using the procedures in ITU-R M.117. The emission measurements will include: the emission spectrum, pulse repetition rate, pulse width, and antenna pattern of the radar. The results of this measurement will be added to the ITS database of government and commercial radar emission measurements.

Project Leader: J. Wayde Allen (303) 497-5871
e-mail wallen@its.bldrdoc.gov

State of Wyoming

In coordination with vendors, test the performance and interoperability of various Project 25 public safety radios in support of the State of Wyoming procurement of new public safety radio equipment.

Project Leader: John M. Vanderau (303) 497-3506
e-mail jvanderau@its.bldrdoc.gov

Scenes from field testing at the Table Mountain field site north of Boulder: ITS and OSM engineers prepare a set of laptop computers for measurements of the aggregate of their wireless emissions (top), and perform testing while taking shelter from the midday sun (middle). Meanwhile, a resident of the field site explores the inside of a vehicle (bottom) (photographs by F.H. Sanders).

ITS Outputs in FY 2005

NTIA Publications

J.W. Allen and J. Ratzloff (Eds.), "Proceedings of the International Symposium on Advanced Radio Technologies, March 1-3, 2005," NTIA Special Publication SP-04-418, Mar. 2005.

> A collection of papers presented at the 2005 International Symposium on Advanced Radio Technologies (see p. 78).

M. Cotton, R. Achatz, J. Wepman, and B. Bedford, "Interference potential of ultrawideband signals - Part 1: Procedures to characterize ultrawideband emissions and measure interference susceptibility of C-band satellite digital television receivers," NTIA Report TR-05-419, Feb. 2005.

> In this study, we hypothesize that ultrawideband (UWB) interference potential can be quantified in terms of UWB signal characteristics. To test this hypothesis, a test system was designed and built to inject UWB signals with known characteristics into a C-band satellite digital television receiver and quantitatively measure interference susceptibility via signal quality metrics (e.g., segment error rate, pre-Viterbi bit error rate, and modulation error ratio) taken from various points in the receiver signal processing chain. UWB signals are characterized by the amplitude probability distribution and power spectral density. Characterization measurements done with a vector signal analyzer provide amplitude and phase information to enable extensive post-measurement capability. This report describes the test setup and procedures in detail. Subsequent reports will provide assessment of interference potential for gated Gaussian noise bursts (Part 2) and modern UWB systems (Part 3).

M. Cotton, R. Achatz, J. Wepman, and P. Runkle, "Interference potential of ultrawideband signals - Part 2: Measurement of gated-noise interference to C-band satellite digital television receivers," NTIA Report TR-05-429, Aug. 2005.

> This report demonstrates that digital television (DTV) susceptibility to gated-noise interference cannot be predicted by interference power characteristics alone. It was found that DTV susceptibility is also dependent on temporal characteristics of the interfering signal and the bandwidth of the DTV receiver. A test system was developed to inject interference with known characteristics into a victim receiver and quantitatively measure susceptibility. In this experiment, a C-band satellite DTV victim receiver was exposed to gated-noise interference, whose temporal characteristics are defined by gating parameters such as on-time, fractional on-time, and off-time. The specific gating parameters considered in this report include on-times of 0.01, 0.10, 1.00, and 10.00 μs and fractional on-times of 1.00, 0.50, 0.25, 0.125, and 0.0625. Results showed that DTV susceptibility was strictly dependent on average power of the interfering signal only when off-times were less than the reciprocal bandwidth of the victim receiver. For longer off-times, however, susceptibility was dependent on the temporal characteristics of the interfering signal. Moreover, high correlation was observed between susceptibility and forward error correction performance of the receiver.

R. Dalke and G. Hufford, "Analysis of the Markov character of a general Rayleigh fading channel," NTIA Technical Memorandum TM-05-423, Apr. 2005.

> It has been proposed that first-order Markov channel models can be used to adequately predict the behavior of a mobile "Rayleigh" fading channel and hence improve the reliability of bidirectional mobile communications systems. Previous authors have addressed this question by applying information theory to the amplitude

statistics of a stationary mobile communications channel. The previous work required numerical analysis to show that for a particular covariance function and range of relevant parameters (i.e., Doppler frequency, symbol period), the channel is approximately first-order Markov. In our analysis, both amplitude and phase information are used to obtain analytic expressions which can easily be used to determine if a non-stationary arbitrary Rayleigh channel is necessarily first-order Markov. The analytic results are given in terms of arbitrary covariance functions that can readily be applied to measurements. In particular, our results show that the previously studied mobile channel is not first-order Markov in character.

J.J. Lemmon, "Radiation pattern analysis of a four-element linear array," NTIA Technical Memorandum TM-05-426, Aug. 2005.

The effects of mutual coupling on the radiation pattern of a four-element linear array were investigated. The objective was to improve the angular resolution of the array for direction-of-arrival estimation by compensating for mutual coupling. It is concluded that the effects of mutual coupling on the performance of the array are not significant, and that the angular resolution of the array is consistent with its theoretical radiation pattern in the absence of mutual coupling. However, it is recommended that the array be calibrated to compensate for systematic errors and any (small) mutual coupling effects that are present.

M.H. Pinson and S. Wolf, "In-service video quality metric (IVQM) user's manual," NTIA Handbook HB-05-424, Apr. 2005.

The purpose of this handbook is to provide a user's manual for the in-service video quality metric (IVQM) tool. IVQM performs automated processing of live video signals. This program runs under the Windows XP® operating system on two PCs communicating through an IP connection. IVQM performs image acquisition, temporal registration, other video calibration (spatial registration, spatial scaling, valid region, and gain/level offset), and video quality estimation. IVQM compares the source video sequence to the destination video sequence (i.e., as output by the video system under test). Each program alternates between video capture and video analysis. Every source/destination video sequence pair is processed through three main steps. First, the sequences are buffered onto a hard drive. Second, the sequences are temporally registered. Third, the video quality of the destination video sequence is estimated. Quality estimates are reported on a scale of zero to one, where zero means that no impairment is visible and one means that the video clip has reached the maximum impairment level. Some video sequences may also be used to estimate other calibration values (spatial registration, spatial scaling, valid region estimation, and gain/level offset). The user has control over how often these other calibration values are calculated.

M.H. Pinson and S. Wolf, "IVQM software," NTIA Software & Data Product SD-05-425, Apr. 2005.

See previous entry for description of the IVQM.

M.H. Pinson and S. Wolf, "Video scaling estimation technique," NTIA Technical Memorandum TM-05-417, Jan. 2005.

Digital video compression algorithms are being deployed that spatially stretch or shrink the video picture. Although small changes in spatial scaling are not usually noticeable to viewers, objective video quality measurement systems may be adversely impacted if the spatial scaling is not corrected. This report describes an algorithm that can be used to automatically measure the amount of spatial scaling present in a video system. This algorithm obtains satisfactory computational complexity by (1) separating the searches for horizontal & vertical scaling factors, (2) using image profiles rather than full images, and (3) using random rather than exhaustive searching techniques.

F.H. Sanders, "Bandwidth dependence of emission spectra of selected pulsed-CW radars," NTIA Technical Memorandum TM-05-431, Aug. 2005.

This technical memorandum describes measurements of the radiated emission spectra of selected maritime radiolocation radar transmitters in multiple bandwidths. The results support published criteria for selection of measurement bandwidths for emission spectra of non-FM pulsed-CW radars. This result complements the radar spectrum engineering criteria (RSEC) measurement procedures described in NTIA Report TR-05-420.

F.H. Sanders, R.L. Hinkle, and B.J. Ramsey, "Measurement procedures for the radar spectrum engineering criteria (RSEC)," NTIA Report TR-05-420, Mar. 2005.

The wide application of radar for various functions makes large demands on the electromagnetic spectrum, and requires the application of effective frequency management for the equipment and systems involved. Requirements for certain equipment characteristics are specified in the NTIA Manual of Regulations and Procedures for Federal Radio Frequency Management to ensure an acceptable degree of electromagnetic compatibility among radar systems, and between such systems and those of other radio services in the frequency spectrum. These standards are called the Radar Spectrum Engineering Criteria (RSEC). This report describes techniques for measuring radar spectrum-related parameters and characteristics for compliance with the RSEC. Measurements for both conventional and advanced radar types are addressed. This report supersedes NTIA Report 84-157 of August 1984.

F.H. Sanders and B.J. Ramsey, "Comparison of radar spectra on varying azimuths relative to the base of the antenna rotary joint," NTIA Technical Memorandum TM-05-430, Aug. 2005.

This technical memorandum describes the results of radiated measurements of the emission spectrum of a maritime radar at varying azimuths relative to the base of the radar transmitter antenna rotary joint. The measurements were performed to address the question of whether the emission spectrum of such a radar might vary as a function of the pointing azimuth of the radar antenna as it rotates due to variation in the joint's voltage standing wave ratio (VSWR) with azimuth. If such variation were to occur, then the radiated spectrum would need to be characterized as a function of azimuth. The measurement results indicate that the emission spectrum of this radar does not vary as a function of transmitter antenna azimuth. It is concluded that this issue is probably not a concern for radar emission measurements in general, and that the radiated spectrum measurement procedures described in NTIA Report TR-05-420 are adequate.

Outside Publications

Articles in Conference Proceedings

J. Randy Hoffman and R.J. Matheson, "RSMS measurement and analysis of LMR channel usage," in "Proceedings of the International Symposium on Advanced Radio Technologies: March 1-3, 2005," J.W. Allen and J. Ratzloff, Eds., NTIA Special Publication SP-05-418, Mar. 2005, pp. 13-19.

The Radio Spectrum Measurement System (RSMS) is used to make a wide range of radio measurements to help manage the federal portion of the radio spectrum. This paper describes a recent set of land mobile radio (LMR) channel occupancy measurements in the Washington, DC, area. These RSMS measurements were made to provide data in support of several projects related to long-term planning of ways to use federal radio bands more efficiently. The measurements were made using new equipment and techniques that digitized spectrum in 5-MHz swaths and processed it to obtain simultaneous signal levels in 400 individual LMR channels. These techniques provided faster measurements than conventional swept-frequency techniques and also allowed enhanced post-processing of the data to remove measurement defects like intermodulation products and impulsive noise.

J.J. Lemmon, "MIMO channel capacity with discrete alphabets," in *Proc. Wireless 2005*, Calgary, Jul. 2005.

> Information theory is used to derive expressions for the channel capacity of MIMO communication systems that use discrete sets of input symbols. The results are compared with the classical Shannon capacity that corresponds to a continuous (Gaussian) set of symbols. The relationships between capacity and signal-to-noise ratio, numbers of transmit and receive antennas, and the number of input symbols are discussed. Example results for various channel conditions are presented.

R.J. Matheson, "Flexible spectrum use rights tutorial - ISART 2005," in "Proceedings of the International Symposium on Advanced Radio Technologies: March 1-3, 2005," J.W. Allen and J. Ratzloff, Eds., NTIA Special Publication SP-05-418, Mar. 2005, pp. 157-167.

> Although "command and control" spectrum management techniques have provided licenses for many specific services since the early days of radio, such licensing may not easily permit new technologies and new services. This paper describes the necessary principles of flexible use spectrum rights, which may allow a wide variety of spectrum uses in a single general-purpose band. Based on the electrospace description of the radio spectrum, these principles allow general aggregation or division of licensed electrospace regions via secondary markets, providing rules for how regulatory limits change under aggregation or division. These flexible-use principles limit transmitter behaviors that tend to create a more difficult operating environment for receivers, while making receivers responsible for handling any remaining interference. Flexible-use principles could provide a basis for real-world flexible-use frequency bands.

T.J. Riley and T.L. Rusyn, "Using a PCS self-interference model to evaluate the effects of cell damage or failure," in "Proceedings of the International Symposium on Advanced Radio Technologies: March 1-3, 2005," J.W. Allen and J. Ratzloff, Eds., NTIA Special Publication SP-05-418, Mar. 2005, pp. 205-211.

> Using a self-interference model developed at the Institute for Telecommunication Sciences (ITS), the effects of system damage, load shifting, and increased traffic on personal communications service (PCS) systems can be studied, allowing emergency service providers to anticipate system availability and the need for supplemental emergency communications equipment. Currently implemented for systems following the ANSI/TIA/EIA 95B standard, this model characterizes the self-interference by producing a multiple-channel multiple-base station air interface signal with a variable number of base stations and channels per base station. The model also includes power control for individual signals, which is an important aspect of the interference level existing in the spectrum. The study of self-interference helps to develop more useful schemes to reduce the interference levels. The change in the aggregate air-interface spectrum is calculated and the resultant signal to interference (C/I) values can be used to determine the change in service quality and the probability of service availability. Any number of scenarios can be developed, depending on the configuration of the system under study and the level of detail desired. Since the model produces a cumulative baseband signal for both the forward and reverse directions, it can be implemented in a real-time hardware channel simulator, or as a component of higher-level software simulation and modeling. Predicted C/I values can be used in software-based network models to anticipate system limitations, traffic bottlenecks, and the probability of overall system failure. The baseband signal produced can be used to generate a simulated traffic signal for the testing and evaluation of commercial equipment. The model is particularly well-suited for independent PCS system evaluation by other Federal agencies, system manufacturers, and service providers.

F. Sanders, "Detection and measurement of radar signals: A tutorial," in "Proceedings of the International Symposium on Advanced Radio Technologies: March 1-3, 2005," J.W. Allen and J. Ratzloff, Eds., NTIA Special Publication SP-05-418, Mar. 2005, pp. 169-181.

> The wide use of radars for various functions makes significant demands on the electromagnetic spectrum. Effective measurement and monitoring of radar emissions is necessary to verify compliance with the legal emission limits specified in the Radar Spectrum Engineering Criteria (RSEC), as set forth by NTIA. Detection and measurement of radar signals is necessary to ensure an acceptable degree of electromagnetic compatibility among radar systems, and between such systems and those of other radio services in the frequency spectrum. This tutorial describes techniques for detecting and measuring radar emissions for compliance with the RSEC and other spectrum management purposes. Techniques for both conventional and advanced radar types are addressed.

F. Sanders, "Technical challenges to spectrum sharing between radars and non-radar (communication) systems," in "Proceedings of the International Symposium on Advanced Radio Technologies: March 1-3, 2005," J.W. Allen and J. Ratzloff, Eds., NTIA Special Publication SP-05-418, Mar. 2005, pp. 21-29.

> To partially satisfy a voracious worldwide appetite for additional spectrum allocations for data and voice communication systems, proposals have been put forth for such systems to share spectrum with radars by operating in bands that have previously been allocated on a primary or co-primary basis for radars alone. Technical justifications for sharing proposals typically include the following claims: Radar systems make little use of existing spectrum allocations, and so there is much radar spectrum available for other uses; radar receiver performance is inherently robust against interference from signals of other services, and therefore radar receivers can operate co-channel with, or at least in the same band as, communication signals; to the extent that interference to radars might occur from non-radar services, it can be limited in principle on some acceptable statistical basis; and finally, if interference to radar receivers due to spectrum sharing in fact is found to be intolerable, it is possible in principle to design and deploy communication systems that will mitigate interference by detecting locally utilized radar frequencies and avoiding operations on those frequencies. All of the above statements contain either technical flaws or implementation challenges that need to be understood by decision makers who must grapple with the radar spectrum sharing issues. This paper discusses the technical challenges of allowing non-radar communication systems to operate in radar spectrum.

S.D. Voran, "A basic experiment on time-varying speech quality," in *Proc. of the 4th International Conference on Measurement of Speech and Audio Quality in Networks (MESAQIN)*, Prague, Czech Republic, Jun. 2005.

> We present a general formulation of a basic open question regarding the perception of time-varying speech quality. We then describe the design, implementation, conduct, and analysis of a practical experiment that addresses a small but fundamental part of that open question. In this experiment, listeners rate the overall speech quality of single sentence stimuli that contain two different levels of nominal speech quality and two transitions between these levels. We present several results including those related to human integration of speech quality and the recency effect. Finally, we discuss these results and suggest potential additional work that might build upon them.

S.D. Voran, "A multiple-description PCM speech coder using structured dual vector quantizers," in *Proc. 2005 IEEE International Conference on Acoustics, Speech, and Signal Processing*, Philadelphia, PA, Mar. 2005.

> We describe a 2-channel multiple-description speech coder based on the ITU-T Recommendation G.711 PCM speech coder. The new coder operates in the PCM code domain in order to exploit the companding gain of PCM. It applies a pair of 2-dimensional structured vector

quantizers to each pair of PCM codes, thus exploiting the correlation between adjacent speech samples. If both quantizer outputs are received, they are combined to generate an approximation to the original pair of PCM codes. If only one quantizer output is received, a coarser approximation is still possible. When using 6 bits/sample/channel (for a total data rate of 96 kbps) the coder provides an equivalent PCM speech quality of 7.3 bits/sample when both channels are working and 6.4 bits/sample when one channel is working.

S.D. Voran, "Multiple-description PCM speech coding by complementary asymmetric vector quantizers," in *Proc. IEEE 2005 Region 5 Conference*, Denver, CO, Apr. 2005.

We describe new 2-channel multiple-description speech coders based on the ITU-T Recommendation G.711 PCM speech coder. The new coders operate in the PCM code domain in order to exploit the companding gain of PCM. They apply pairs of complementary asymmetric 2-dimensional vector quantizers to each pair of PCM codes, thus exploiting the correlation between adjacent speech samples. If both quantizer outputs are received (two channels working), they are combined to generate an approximation to the original pair of PCM codes. If only one quantizer output is received (one channel failed, one channel working), a coarser approximation is still possible. The vector quantizers use rectangular cells, and the aspect ratio of the cells controls the speech-quality trade-off between the two-channel and one-channel cases.

S. Wolf and M.H. Pinson, "Low bandwidth reduced reference video quality monitoring system," in *Proc. First International Workshop on Video Processing and Quality Metrics for Consumer Electronics*, Scottsdale, AZ, Jan. 2005.

This paper presents a new reduced reference (RR) video quality monitoring system that utilizes less than 10 kbits/s of reference information from the source video stream. This new video quality monitoring system utilizes feature extraction techniques similar to those found in the NTIA General Video Quality Model (VQM) that was recently standardized by the American National Standards Institute (ANSI) and the International Telecommunication Union (ITU). Objective to subjective correlation results are presented for 18 subjectively rated data sets that include more than 2500 video clips from a wide range of video scenes and systems. The method is being implemented in a new end-to-end video quality monitoring tool that utilizes the Internet to communicate the low bandwidth features between the source and destination ends.

Journal Articles

C. Dvorak and N. Seitz, "Signalling and interworking challenges for quality of service in the next-generation network," *The Journal of the Communications Network 3*, Part 2, pp. 14-23, Apr.-Jun. 2004.

A key challenge for next-generation networks (NGN) is the standardisation of a quality-of-service (QoS) solution that supports voice telephony and other real-time services with assured quality levels, requiring end-to-end signalling that must work across multiple IP-based networks. This paper summarises representative industry efforts to standardise IP network QoS signalling capabilities for NGN, and identifies one very fundamental area - the standardization of technology-independent IP QoS signalling requirements - where focused industry effort is urgently needed.

P. Papazian, "Basic transmission loss and delay spread measurements for frequencies between 430 and 5750 MHz," *IEEE Transactions on Antennas and Propagation 53*, No. 2, pp. 694-701, Feb. 2005.

Impulse response radiowave propagation measurements from an urban area of Denver, CO, are described. The basic transmission loss and delay spread are used to characterize the mobile communications environment. These metrics are quantified using path loss slope and delay spread statistics. By analyzing the results versus carrier frequency, the relative propagation impairments at 430, 1350, 2260, and 5750 MHz are compared. It was found that the path loss slope increased on average by 11 dB/dec and the median delay spread decreased from 0.7 to 0.3 s over the decade of frequencies measured.

Unpublished Presentations

N. DeMinco, "Antenna factor determination for antennas in the near field of a large radiating aperture," International Union of Radio Science (URSI) Meeting, Boulder, Colorado, Jan. 8, 2005.

J.E. Kub, "LabVIEW with databases automates testing of land mobile radios for public safety," National Instruments Technical Symposium, Colorado School of Mines, Golden, Colorado, Nov. 18, 2004.

R. Matheson, "The radio spectrum," Annual Conference of Women in Cable and Telecommunications (WICT), Broomfield, Colorado, Nov. 11, 2004.

E. Nelson, "Managing intersystem interference between analog and digital two-way radio systems," International Wireless Communications Expo (IWCE), Las Vegas, Nevada, Apr. 2005.

E. Nelson, presentation of proposed P25 Compliance Assessment Program details to the American Council of Independent Laboratories (ACIL), IEEE EMC Society meeting, Chicago, Illinois, Aug. 2005.

T.J. Riley, "Simulation of PCS traffic loading and interference due to cell damage or failure," International Union of Radio Science (URSI) Meeting, Boulder, Colorado, Jan. 5, 2005.

F.H. Sanders, "Factors to consider for intersystem EMC," ITU-R Radar Seminar, Geneva, Sep. 24, 2005.

F.H. Sanders, "Radar emission measurement techniques," 51st Annual Tri-Service Radar Symposium, Monterey, California, Jun. 2005.

S.D. Voran, "Coding and quality of speech and music," Invited Guest Lecture at the University of Northern Colorado, Greeley, Colorado, Apr. 19, 2005.

Conferences Sponsored by ITS

International Symposium on Advanced Radio Technologies (ISART 2005)

The International Symposium on Advanced Radio Technologies (ISART 2005) was held March 1-3, 2005. This symposium explores the current state of the radio art with an eye towards forecasting the use of wireless technology in the future. In order to accomplish this goal, ISART brings together a diverse collection of people from academia, business, and government agencies to discuss the interplay between technological "how-to," the possibilities and restrictions created by regulation and policy, and the economic motivation of the business world. For more information see: http://www.its.bldrdoc.gov/meetings/art/.

ISART attendees mingling in the lobby outside the auditorium (photograph by W.A. Kissick).

Standards Leadership Roles

David J. Atkinson, Technical Coordinator for the development of a Justice and Public Safety XML Data Model and Data Element Dictionary, through the XML sub-committee of the Global Justice Information Sharing Initiative's Infrastructure/ Standards Working Group.

Randall S. Bloomfield, Federal Representative on Project 25/34 Steering Committee; Vice-Chair of the ISSI Task Group (ISSI TG) and Vice-Chair of the P25 Systems Architecture Working Group (PSAWG) (both within the APCO Project 25 Interface Committee); Editor of Project 25 Statement of Requirements (P25 SoR).

Paul M. McKenna, Chair of ITU-R U.S. Study Group 3 (Radiowave Propagation); U.S. Chair of Working Party 3K; Chair of (international) Subgroup 3K-2 to Working Party 3K; Chair of Drafting Group for 3M-3B.

William J. Pomper, Chair of APCO/NASTD/FED Project 25 Encryption Task Group.

Timothy J. Riley, Member of Alliance for Telecommunications Industry Solutions (ATIS) committee WTSC-G3GRA (Wireless Technologies and Systems Committee — Radio Aspects of GSM/3G and Beyond) and issue champion for development of a document addressing interference issues affecting wireless communication systems.

Frank Sanders, Chair of ITU-R Radar Correspondence Group (radar technical spectrum issues); Delegate to ITU-R Working Party 8B (radar spectrum allocation and sharing) and Joint Rapporteur Group 1A-1C-8B (radar spectrum efficiency issues).

Neal B. Seitz, Vice Chair of ITU-T Study Group 13 (Next Generation Networks); Chair of ITU-T Study Group 13 Working Party 4 (OAM and QoS); Vice Chair of ATIS Network Performance, Reliability, and Quality of Service Committee (PRQC).

Bruce R. Ward, Editor for TIA102-BACx, "ISSI measurement methods for voice services," and TIA102-BACx, "ISSI performance recommendations for voice services."

Arthur Webster, Co-chair of Video Quality Experts Group (VQEG); Rapporteur for Question 14/9 (Objective and subjective methods for evaluating perceptual audiovisual quality in multimedia services within the terms of Study Group 9) in ITU-T Study Group 9 (Integrated broadband cable networks and television and sound transmission); Chair of Joint Rapporteur Group on Multimedia Quality Assessment (JRG-MMQA); Chair of ATIS PRQC's Security Task Force. Study Group 9's Liaison Officer for the ITU's Telecommunications for Disaster Relief and Mitigation - Partnership Co-ordination Panel (PCP-TDR).

Representative Technical Contributions

Contributions listed below are a sample of the extensive standards work that ITS does each year.

Audio Quality

- Revision of T1.801.04-1997 (R2002), "Multimedia communications delay, synchronization, and frame rate," ATIS PRQC-2005-064, Apr. 2005 (S.D. Voran, N.B. Seitz).
- "An algorithm for near real-time tracking of time-varying delays in telecommunications speech signals," ATIS PRQC-2005-065, Apr. 2005 (S.D. Voran).
- Proposed Revised Text for ANS T1.801.04, ATIS PRQC-2005-094, Jun. 2005 (N.B. Seitz).
- LB A013 Comment Consideration Report, ATIS PRQC-2005-147, Aug. 2005 (S.D. Voran).
- Text for ANS T1.801.04, ATIS PRQC-2005-148, Aug. 2005 (S.D. Voran).

Emergency Telecommunications Service Projects

- "Availability and restorability aspects of emergency telecommunications service (ETS)," Draft Technical Report, T1A1/2003-210, Oct. 2004 (A. Webster).
- "User plane priority levels for IP networks and services," Draft Technical Report, T1A1/2003-196R3, Nov. 2004, approved as an ATIS Technical Report FY 2005 (A. Webster).
- "Proposed revisions to draft new Recommendation J.pref (formerly J.tdr.1) - Specifications for preferential telecommunications over IPCablecom networks," ITU-T Study Group 9, Jan. 2005 (A. Webster).

- "Service restoration priority levels for IP networks," Initial Text for Draft Technical Report, ATIS PRQC-2005-021, Feb. 2005, report approved FY 2005 (A. Webster).
- "Overview of standards in support of emergency telecommunications service (ETS)," Draft Revision of T1.TR.79-2003, PRQC-2005-105, Jun. 2005 (A. Webster).
- "Reliability and survivability aspects of emergency telecommunications services," ATIS Technical Report, report approved FY 2005 (A. Webster).

High-power Radars and Spectrum Sharing

- Proposed Modification to Radar Emission Spectrum Measurement Bandwidth Limit in Recommendation M.1177-3, ITU-R WP-8B (F. Sanders).
- Proposed Modification to Radar Emission Spectrum Antenna Rotation Procedure in Recommendation M.1177-3, ITU-R WP-8B (F. Sanders).

APCO Project 25

- "Experiment 3 MOS test plan for vocoder technology for Project 25 Phase 2," APCO Project 25 Interface Committee Vocoder Task Group, Denver, CO, Aug. 2005 (D. Atkinson).
- Discussion paper: "Migration considerations and the "interim" FSI standard," Fixed Station Interface Task Group (FSITG) (P25/TR-8), Jun. 2005 (R. Bloomfield).
- Planned future ISSI standardization area: ISSI engineering guidelines, revised draft PSAWG functional description, PSAWG (P25/TR-8), Jun. 2005 (R. Bloomfield).
- Issue E of the Draft Revised Project 25 Statement of Requirements, Project 25 User Needs Subcommittee (P25 UNS), Sep. 2005 (R. Bloomfield).
- Issue J of planned new TIA/ANSI standard: Project 25 ISSI measurement methods for voice services, ISSI TG (P25/TR-8), Oct. 2004 (R. Bloomfield).
- Issue I of planned new TIA/ANSI standard: Project 25 ISSI performance specifications for voice services, ISSI TG (P25/TR-8), Oct. 2004 (R. Bloomfield).

Quality of Service

- "QoS provisions in IEEE 802.11-based wireless LANs," ATIS PRQC-2005-069, Apr. 2005 (N.B. Seitz).
- "Development of an NGN QoS program management plan," ATIS PRQC-2005-117, Jun. 2005 (N.B. Seitz).
- "SIP-based call processing performance in NGNs," ATIS PRQC-2005-143, Aug. 2005 (N.B. Seitz).

Ultrawideband

- "Derivation of the necessary bandwidth (-20 dB bandwidth) and -40 dB bandwidth formulas for CW pulsed modulated waveforms," US Radiocommunications Sector Fact Sheet, Document USJRG05-07 Rev.1, Mar. 2005 (L. Brunson and R. Dalke).

Video Quality

- "Report of JRG-MMQA meetings June and October 2004," ITU-T Study Group 9 (also sent to SG12), Jan. 2005 (A. Webster).

Abbreviations/Acronyms

2D	two-dimensional
3D	three-dimensional
3G	third **g**eneration

A

AAR	**A**ssociation of **A**merican **R**ailroads
AGILE	**A**dvanced **G**eneration of **I**nteroperability for **L**aw **E**nforcement
ANS	**A**merican **N**ational **S**tandard
ANSI	**A**merican **N**ational **S**tandards **I**nstitute
APCO	**A**ssociation of **P**ublic-Safety **C**ommunications **O**fficials
APD	**A**mplitude **P**robability **D**istribution
APM	**A**dvanced **P**ropagation **M**odel
AQMS	**A**udio **Q**uality **M**easurement **S**ystem
ASC	**A**verage **S**ignal **C**apacity
ATB	**a**ntenna **t**est**b**ed
ATIS	**A**lliance for **T**elecommunications **I**ndustry **S**olutions

B

BAWT	**B**roadband **A**rbitrary **W**aveform **T**ransmitter
BBTG	**B**road**B**and **T**ask **G**roup

C

C/I	**c**arrier to **i**nterference
CD	**c**ompact **d**isk
CDA	**C**ode **D**omain **A**nalyzer
CDMA	**C**ode **D**ivision **M**ultiple **A**ccess
CIP	**C**ritical **I**nfrastructure **P**rotection
CONUS	**Con**tinental **U.S.**
COPS	Office of **C**ommunity **O**riented **P**olicing **S**ervice
CRADA	**C**ooperative **R**esearch **a**nd **D**evelopment **A**greement
CRPL	**C**entral **R**adio **P**ropagation **L**aboratory
CSPM	**C**ommunication **S**ystem **P**erformance **M**odel
CSPT	**C**ommunication **S**ystem **P**lanning **T**ool
CW	**c**ontinuous **w**ave

D

DAQ	**D**elivered **A**udio **Q**uality
dB	**d**eci**b**el
DFS	**D**ynamic **F**requency **S**election
DHS	**D**epartment of **H**omeland **S**ecurity
DLL	**D**ynamic **L**ink **L**ibrary
DOC	**D**epartment **o**f **C**ommerce
DOD	**D**epartment **o**f **D**efense
DOJ	**D**epartment **o**f **J**ustice
DP-UWB	**D**ither-**P**ulse **U**ltra**w**ide**b**and
DSCP	**D**igital **S**ampling **C**hannel **P**robe
DSL	**D**igital **S**ubscriber **L**ine
DS-UWB	**D**irect-**S**equence **U**ltra**w**ide**b**and
DTV	**d**igital **t**elevision

E

EIA	**E**lectronic **I**ndustries **A**lliance
EMC	**e**lectro**m**agnetic **c**ompatibility
EMOS	**E**stimated **M**ean **O**pinion **S**core
EMS	**E**mergency **M**edical **S**ervices
ESSA	**E**nvironmental **S**cience **S**ervices **A**dministration
ETS	**E**mergency **T**elecommunications **S**ervice
ETSI	**E**uropean **T**elecommunications **S**tandards **I**nstitute
EVA	**Ev**aluation License **A**greement

F

FCC	**F**ederal **C**ommunications **C**ommission
FED	**Fed**eral
FGNGN	**F**ocus **G**roup on **NGN**
FM	**f**requency **m**odulation
FPGA	**F**ield **P**rogrammable **G**ate **A**rray
FPIC	**F**ederal **P**artnership for **I**nteroperability **C**ommunications
FQT	**F**ormal **Q**ualification **T**est
FTP	**F**ile **T**ransfer **P**rotocol
FY	**F**iscal **Y**ear

G

GB	**g**iga**b**yte
GCC	**G**roup **C**ommunications **C**enter
GETS	**G**overnment **E**mergency **T**elecommunications **S**ervice
GHz	**g**iga**h**ert**z**
GIF	**G**raphics **I**nterchange **F**ormat
GIS	**G**eographic **I**nformation **S**ystem
GJXDM	**G**lobal **J**ustice **X**ML **D**ata **M**odel
GLOBE	**G**lobal **L**and **O**ne-km **B**ase **E**levation
GMF	**G**overnment **M**aster **F**ile
GPS	**G**lobal **P**ositioning **S**ystem
GSM	**G**lobal **S**ystem for **M**obile
GUI	**G**raphical **U**ser **I**nterface

H

HAAT	**H**eight **A**bove **A**verage **T**errain calculation program
HD	**h**igh **d**efinition
HDTV	**H**igh **D**efinition **T**ele**v**ision
HF	**h**igh **f**requency
HTML	**H**yper**t**ext **M**arkup **L**anguage

I

I/O	**i**nput/**o**utput
ICEAREA	a version of ICEPAC (see below) that produces area coverage predictions.
ICEPAC	**I**onospheric **C**ommunications **E**nhanced **P**rofile **A**nalysis and **C**ircuit Prediction Program
IEEE	**I**nstitute of **E**lectrical and **E**lectronics **E**ngineers
IETF	**I**nternet **E**ngineering **T**ask **F**orce
IF	**i**ntermediate **f**requency
INR_{TOV}	**i**nterference-to-**n**oise **r**atio at **t**hreshold **o**f **v**isibility
IP	**I**nternet **P**rotocol
IPG	**I**ntersessional **P**lanning **G**roup
IRL	**I**nteroperability **R**esearch **L**aboratory
ISART	**I**nternational **S**ymposium on **A**dvanced **R**adio **T**echnologies
ISM	**I**ndustrial, **S**cientific, and **M**edical
ISSI	**I**nter-rf **S**ub**s**ystem **I**nterface
IT	**I**nformation **T**echnology
ITM	**I**rregular **T**errain **M**odel
ITS	**I**nstitute for **T**elecommunication **S**ciences
ITSA	**I**nstitute for **T**elecommunication **S**ciences and **A**eronomy
ITU	**I**nternational **T**elecommunication **U**nion
ITU-R	**I**nternational **T**elecommunication **U**nion — **R**adiocommunication Sector
ITU-T	**I**nternational **T**elecommunication **U**nion — **T**elecommunication Standardization Sector
IVQM	**I**n-Service **VQM**

J

JRG	**J**oint **R**apporteur(s) **G**roup

K

kbps	**k**ilo**b**its **p**er **s**econd
kHz	**k**ilo**h**ert**z**

L

LAN	**L**ocal **A**rea **N**etwork
LMDS	**L**ocal **M**ultipoint **D**istribution **S**ervice
LMR	**L**and **M**obile **R**adio
LOS	**l**ine **o**f **s**ight

M

MB-OFDM	**M**ulti-**B**and **O**rthogonal **F**requency-**D**ivision **M**ultiplexing
Mb/s, Mbps	**m**ega**b**its **p**er **s**econd
MD	**M**ultimedia **D**efinition
MDC	**M**ulti-**D**escriptive **C**oding
MHz	**m**ega**h**ert**z**
MIMO	**M**ultiple **I**nput **M**ultiple **O**utput
MM	**m**ulti**m**edia
MMQA	**M**ulti**m**edia **Q**uality **A**ssessment
MPLS	**M**ulti**p**rotocol **L**abel **S**witching
MSTV	Association for **M**aximum **S**ervice **T**ele**v**ision

N

NASA	**N**ational **A**eronautics and **S**pace **A**dministration
NASTD	**N**ational **A**ssociation of **S**tate **T**elecommunications **D**irectors
NCS	**N**ational **C**ommunications **S**ystem
NDRS	**N**ational **D**istress & **R**esponse **S**ystem
NGN	**N**ext **G**eneration **N**etwork
NIEM	**N**ational **I**nformation **E**xchange **M**odel
NIJ	**N**ational **I**nstitute of **J**ustice
NIST	**N**ational **I**nstitute of **S**tandards and **T**echnology
NOAA	**N**ational **O**ceanic and **A**tmospheric **A**dministration
NRSSC	**N**etwork **R**eliability and **S**ecurity **Sub**committee
NS/EP	**N**ational **S**ecurity and **E**mergency **P**reparedness
NTIA	**N**ational **T**elecommunications and **I**nformation **A**dministration
NWR	**N**OAA **W**eather **R**adio
NWS	**N**ational **W**eather **S**ervice

O

OAM	**O**peration, **A**dministration and **M**aintenance
OLES	**O**ffice of **L**aw **E**nforcement **S**tandards
OMB	**O**ffice of **M**anagement and **B**udget
OQPSK	**O**ffset **Q**uadrature **P**hase-**S**hift **K**eying
OSM	**O**ffice of **S**pectrum **M**anagement
OT	**O**ffice of **T**elecommunications
OTP	**O**ffice of **T**elecommunications **P**olicy

P

P25	**P**roject **25**
PBS	**P**ublic **B**roadcasting **S**ystem
PC	**p**ersonal **c**omputer
PCM	**P**ulse **C**ode **M**odulation
PCS	**P**ersonal **C**ommunications **S**ervices
PDA	**p**ersonal **d**igital **a**ssistant
PDD	**P**residential **D**ecision **D**irective
PESQ	**P**erceptual **E**valuation of **S**peech **Q**uality
PN	**p**seudo-**n**oise
PRQC	Network **P**erformance, **R**eliability and **Q**uality of Service **C**ommittee
PSAWG	**P**25 **S**ystems **A**rchitecture **W**orking **G**roup
PSTN	**P**ublic **S**witched **T**elephone **N**etwork

Q

QoS	**Q**uality **o**f **S**ervice
QPSK	**Q**uadrature **P**hase-**S**hift **K**eying

R

R&D	**r**esearch and **d**evelopment
RCG	**R**adar **C**orrespondence **G**roup
RF	**r**adio **f**requency
RLAN	**R**adio **L**ocal **A**rea **N**etwork
RMS	**r**oot **m**ean **s**quare
RR	**R**educed **R**eference
RRC	**R**egional **R**adio **C**onference
RR-NR	**R**educed **R**eference – **N**o **R**eference
RSEC	**R**adar **S**pectrum **E**ngineering **C**riteria
RSL	**r**eceived **s**ignal **l**evel
RSMS	**R**adio **S**pectrum **M**easurement **S**cience
RSMS-4	**4**th Generation **RSMS**

S

SAFECOM	Public **Safe**ty Wireless **Com**munications
SAME	**S**pecific **A**rea **M**essage **E**ncoding
SC	**S**ignal **C**apacity
SD	**S**tandard **D**efinition
SDMA	**S**pace **D**ivision **M**ultiple **A**ccess
SDTS	**S**patial **D**ata **T**ransfer **S**tandard
SG	**S**tudy **G**roup
SIP	**S**ession **I**nitiation **P**rotocol
SIPRNET	**S**ecret **I**nternet **P**rotocol **R**outable **Net**work
SIT	**S**ystem **I**ntegration **T**est

SLA	**S**ervice **L**evel **A**greement
SMPTE	**S**ociety of **M**otion **P**icture and **T**elevision **E**ngineers
SNR	**s**ignal to **n**oise **r**atio
SOR	**S**tatement **o**f **R**equirements
SUT	**S**ystem **U**nder **T**est

T

T&E	**t**est and **e**valuation
TA Services	**T**elecommunications **A**nalysis **Services**
TB	**t**era**b**yte
TG	**T**ask **G**roup
TIA	**T**elecommunications **I**ndustry **A**ssociation
TM	**T**echnical **M**emorandum
TR	**T**echnical **R**eport
TSB	**T**elecommunications **S**ystems **B**ulletin

U

UHF	**u**ltra **h**igh **f**requency
URL	**U**niform **R**esource **L**ocator
URSI	**I**nternational **U**nion of **R**adio **S**cience
US	**U**nited **S**tates
USCG	**U.S. C**oast **G**uard
USGS	**U.S. G**eological **S**urvey
UWB	**u**ltra**w**ide**b**and

V

VHF	**v**ery **h**igh **f**requency
VOACAP	**V**oice **o**f **A**merica **C**ommunications **A**nalysis and **P**rediction program
VoIP	**V**oice **o**ver **I**nternet **P**rotocol
VPN	**V**irtual **P**rivate **N**etwork
VQEG	**V**ideo **Q**uality **E**xperts **G**roup
VQM	**V**ideo **Q**uality **M**etric
VSA	**v**ector **s**ignal **a**nalyzer
VSG	**v**ector **s**ignal **g**enerator
VSWR	**v**oltage **s**tanding **w**ave **r**atio

W

WAS	**W**ireless **A**ccess **S**ystem
W-CDMA	**W**ideband **CDMA**
WCTF	**W**ireless **C**ommunications **T**ask **F**orce
Wi-Fi	**Wi**reless **Fi**delity
WLAN	**W**ireless **LAN**
WMO	**W**ireless **M**anagement **O**ffice
WNRC	**W**ireless **N**etworks **R**esearch **C**enter
WP	**W**orking **P**arty
WPAN	**W**ireless **P**ersonal **A**rea **N**etwork
WRC	**W**orld **R**adiocommunication **C**onference

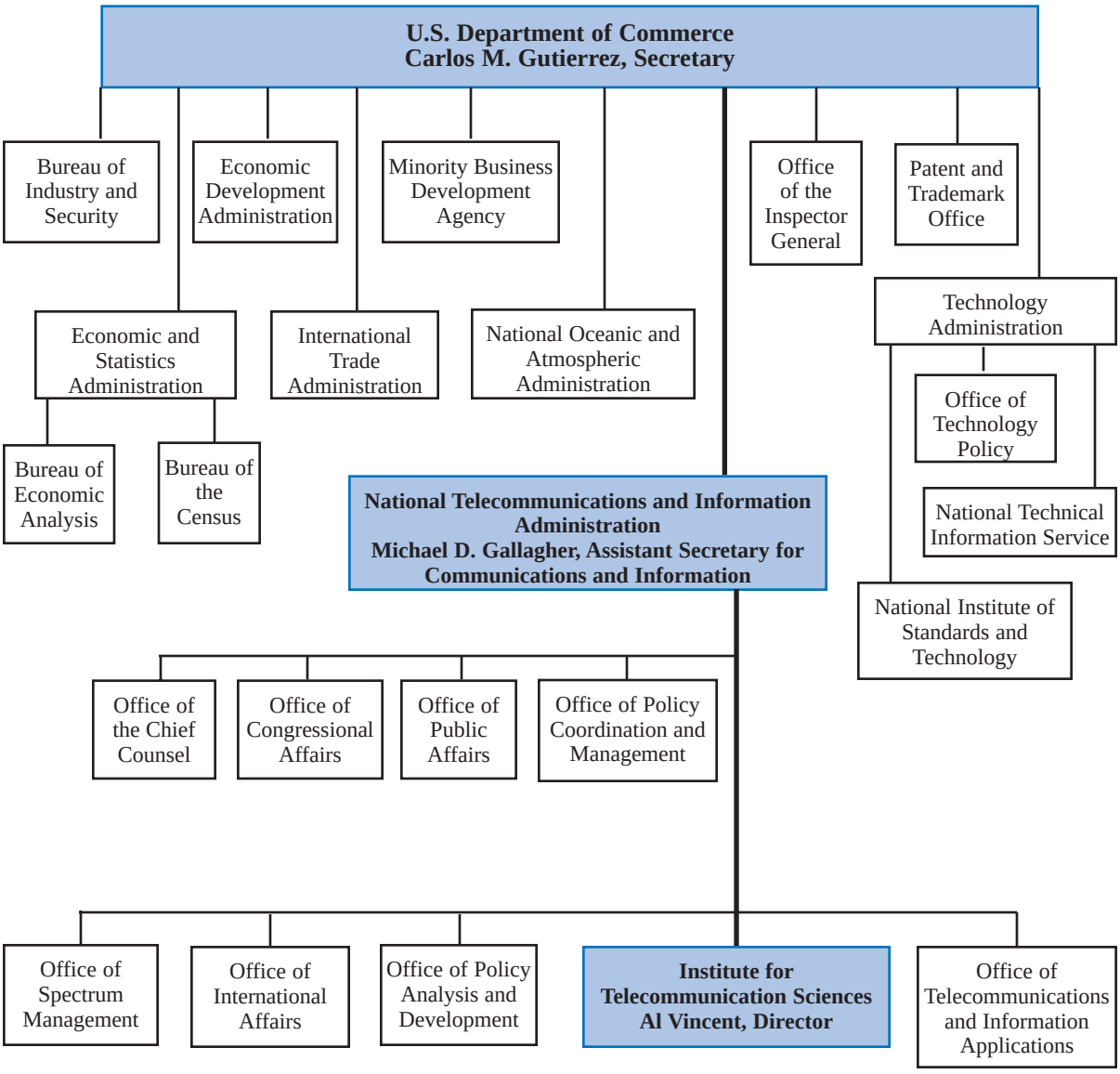
X

XML	E**x**tensible **M**arkup **L**anguage

Y

YIG	**y**ttrium-**i**ron-**g**arnet

DOC/NTIA Organization Chart



ITS Organization Chart

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