2009

Institute for Telecommunication Sciences

TECHNICAL PROGRESS REPORT

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

ITS
Institute for Telecommunication Sciences

Boulder, Colorado

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Institute for Telecommunication Sciences

FY 2009 Technical Progress Report

U.S. Department of Commerce

**Lawrence E. Strickling, Assistant Secretary
for Communications and Information**

May 2010

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 are necessarily the best available for the particular application or use.

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ITS contributed technology to PSCR controlled burns in Carmel, Indiana. The photographs above show ITS equipment (top) positioned to record the burn (bottom) (photographs courtesy of Touchstone Consulting Group).

ITS Overview

Organization

The Institute for Telecommunication Sciences (ITS) is the research and engineering laboratory of the National Telecommunications and Information Administration (NTIA) of the U.S. Department of Commerce (DOC). ITS provides research and engineering that is critical to continued U.S. leadership in telecommunications technology.

Mission

ITS works with Government agencies and private organizations to explore, understand, and improve the use of telecommunications technologies and principles; investigate and invent new technologies; and overcome telecommunications challenges. We use our research and expertise to contribute to standards creation, analyze new and emerging technologies, and improve telecommunications trade opportunities.

Program Areas

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, and
- Telecommunications Theory.

The Director's Office supports these areas in budget and administrative functions.

Facilities

The Institute's world-class facilities and capabilities include:

- Audio-Visual Laboratories
- Public Safety RF Laboratory
- Public Safety Audio and Video Laboratories
- Radio Spectrum Measurement Science (RSMS) Program
- Secure Internet (SIPRNET)
- Table Mountain Field Site/Radio Quiet Zone
- Telecommunications Analysis Services

For more information about these and other resources at ITS, see *Tools and Facilities*, page 73.

Employees

ITS' staff of Federal employees have strong engineering and scientific skills and experience. The majority of employees are electronics engineers; the rest are mathematicians, physicists, computer scientists, and administrative staff.

Sponsors

ITS provides a cost-effective, expert resource that supports many Federal agencies and industry organizations. ITS' policy stipulates that research sponsored by other agencies must contribute to NTIA's overall program and must support the goals of the Department of Commerce (DOC).

Government

Activities and programs at ITS are sponsored by the DOC and other Federal agencies. Agency sponsors that provide significant support include the National Institute of Standards and Technology's Office of Law Enforcement Standards, the Department of Homeland Security, the Department of Transportation, the Department of Defense, the National Archives, and the National Weather Service.

Industry

ITS supports private sector telecommunications research 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 (FLC), formally chartered by the Federal Technology Transfer Act in 1986.

CRADAs with other research organizations, telecommunications service providers, and equipment manufacturers support technology transfer and commercialization of telecommunications products and services, which are major goals of the DOC. ITS has had CRADAs with large companies as well as with small start-ups. Partnerships such as these enhance synergies between entrepreneurial ventures and broad national goals.

Capabilities and Expertise

ITS is one of the world's leading laboratories for telecommunications research. Some areas of expertise include:

Radio Research and Spectrum Measurement

ITS measures emission characteristics of Federal transmitter systems, and identifies and resolves radio frequency interference. We incorporate field measurement data into our signal propagation models, and explore advanced antenna designs

Communication Systems and Networks

ITS plans, implements, and evaluates telecommunication systems and networks.

Public Safety Interoperability

ITS facilitates inter-connectivity and interoperability between services and technologies used by public safety organizations.

Standards Development

For many years, ITS has provided and continues to provide leadership and technical contributions in national and international telecommunication standards committees. OMB Circular A-119 provides the ground rules and encouragement for Federal agency involvement in voluntary consensus standards development.

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, ultrawideband, and Dynamic Spectrum Access.

Audio and Video Quality Research

For over 25 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.

Benefits

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 engineering tools to support negotiations provide support for 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.

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, U.S. Department of Commerce. A new facility was built for CRPL in Boulder, Colorado, and dedicated by President Eisenhower in September 1954. In 1965, CRPL joined the Environmental Science Services Administration (ESSA) and was renamed the Institute for Telecommunication Sciences and Aeronomy (ITSA).

In 1967, ITSA split into four laboratories: Aeronomy, Space Research, Wave Propagation, and the Institute for Telecommunication Sciences (ITS). In 1970, Executive Order 11556 established the Office of Telecommunications (OT) within the Department of Commerce 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 engineering support to NTIA, while continuing to assist other Federal agencies on a reimbursable basis. Over the last two decades, ITS has pursued cooperative research with U.S. industry and universities under the provisions of the Federal Technology Transfer Act of 1986.

* * *

This Progress Report summarizes technical contributions made by ITS during Fiscal Year 2009 to both the public and private sectors.

The Department of Commerce Boulder Laboratories in winter 2006 (photograph by J.R. Hoffman).

ITS staff members performing Radar Spectrum Engineering Criteria (RSEC) compliance measurements within the RSMS 4 mobile RF shielded enclosure (photograph by J.R. Hoffman).

ITS staff members performing system verification tests in preparation for radiated emissions measurements of Land Mobile Radios (photograph by J.R. Hoffman).

An ITS staff member setting up the ITS Dynamic Frequency Selection test system in preparation for product surveillance testing for the Spectrum and Propagation Measurements Division (photograph by J. Carroll).

An ITS staff member adjusting instrument settings while evaluating the detection sensitivity of a Dynamic Spectrum Access device (photograph by I. Tobias).

Spectrum and Propagation Measurements

In the last two decades, advances in microelectronics have truly democratized the radio spectrum. This is most evident in the exponential growth of commercial mobile radio services and other wireless consumer devices. Also, demand to more fully exploit the available radio spectrum to foster even more new services has increased.

The radio spectrum management agencies, NTIA and the FCC, have several techniques to accommodate this new demand. One approach is spectrum aggregation and reallocation to new licensees or to unlicensed bands. In instances where incumbent systems cannot be relocated, spectrum sharing has been adopted. More recently, as more computational power and intelligence is available to radio systems, the opportunities for dynamic spectrum access to multiple radio bands is being investigated.

Each approach involves a myriad of complex technical and economic trade-offs necessary to balance the requirements of sophisticated new services with the integrity of the legacy, incumbent radio systems or services. The Spectrum and Propagation Measurements Division fills a specialty role in the emerging science of electromagnetic compatibility by using the latest radio frequency measurement tools and methods to evaluate the implications of new radio services. To assess the technical implications of proposed policy changes the division uses measurements of spectrum usage, evaluations of the compatibility of disparate radio systems, and quantitative and qualitative assessments of receiver susceptibility to interference and noise. The division's studies serve as the technical basis for new spectrum policies and rulemakings.

The following areas of emphasis are indicative of the work done recently in this division to support NTIA, other Federal agencies, academia, and private industry.

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Areas of Emphasis

Radio Spectrum Measurement Science (RSMS) Program The RSMS program encompasses the equipment and operational expertise employed in sophisticated radio frequency measurements. The program supports continuous improvements in measurement system capabilities and performance in both the near and long term. This culminates in enhanced engineering expertise and development and deployment of a sophisticated toolbox of laboratory equipment, analysis tools, and mobile facilities to assess spectrum occupancy, usage, and electromagnetic compatibility, and to resolve interference problems. Two RSMS projects are funded by NTIA: RSMS Operations and RSMS 4th Generation System Development.

Table Mountain Research Program The Table Mountain Field Site is the principal experimental field site for the Department of Commerce Boulder Laboratories. Designated by Congress as a protected radio quiet zone where the magnitude of external signals is restricted, the site facilitates various advanced research and measurement programs. Research at this site includes development and evaluation of measurement methods for spectrum occupancy, radio noise, antenna design, laser testing, and radar emissions conducted through NTIA funding as well as cooperative research agreements with non-Federal entities. These projects are funded by NTIA and private organizations.

Spectrum Sharing Innovation Test-Bed Pilot Program Dynamic Spectrum Access (DSA) describes the second generation of cognitive radios, which contain greater processing power, allowing greater frequency agility and better adaptation to the radio environment, minimizing interference to incumbent radio systems. The division is presently spearheading Test-Bed measurements to assess the capabilities of the latest state of the art DSA devices. The project is funded by NTIA/OSM.

Radio Noise and Spectrum Occupancy Measurement Research ITS engineers are developing a next generation noise measurement system based on Vector Signal Analyzer (VSA) technology. VSA technology captures magnitude and phase information and allows for wider bandwidth noise measurements than those historically conducted at ITS. The project is funded by NTIA.

RSMS Operations

Outputs

- Measurements to resolve interference into a 5-GHz Terminal Doppler Weather Radar (TDWR) from Dynamic Frequency Selection (DFS) devices.
- Measurements of harmonic emissions in the GPS bands from Land Mobile Radio (LMR) systems.
- Measurements to verify detection capability of off-the-shelf 5-GHz DFS devices using Federal Communications Commission (FCC) certification waveforms.

Overview

The Radio Spectrum Measurement Science (RSMS) program has the task of performing critically needed and time-sensitive radio signal measurements that facilitate Federal Government spectrum allocation decisions and policy making. As stated under Departmental Organization Order 25-7, ITS is responsible for identifying measurements that will guide the effective and efficient use of the spectrum. RSMS program managers coordinate with the NTIA Office of Spectrum Management (OSM) to ensure that all spectrum research needs are being met. ITS, through the RSMS Operations Project, provides OSM and the executive branch with critically needed radio spectrum data, data analysis, reports, and summaries. RSMS encompasses the following types of measurements:

1. Spectrum surveys and channel usage,
2. Equipment characteristics and compliance,
3. Interference resolution and electromagnetic compatibility, and
4. Signal coverage and quality.

In FY 2009, several different measurements were performed in support of the RSMS mission.

LMR System Harmonic Emission Measurements

In 2004, the White House released a new national policy on space-based positioning, navigation, and timing (PNT) services. The PNT policy is designed to ensure uninterrupted availability of these services; to meet the growing needs of the national security, economic, and civil sectors; and to maintain the United States' pre-eminence in this area. In response to the national PNT Policy, NTIA developed a plan to address the Department of Commerce (DOC) responsibilities in managing and protecting the frequency bands used for current and evolving PNT services.

To characterize the emission levels of Federal systems in the GPS frequency bands, OSM, in conjunction with ITS, developed a measurement effort comprised of three subtasks. In subtask 1 (completed), Federal systems that could possibly generate emissions (adjacent and harmonic) in the GPS bands were identified and coordinated with the Federal agency representatives of the Interdepartment Radio Advisory Committee (IRAC). In subtask 2 (in progress), the emission levels in the GPS bands from selected Federal systems identified in subtask 1 will be measured. Subtask 3 (pending) will use the results of the emission measurements and previously developed interference scenarios to assess how closely the actual emission levels compare to the existing standards.

In support of subtask 2, ITS and OSM characterized the harmonic emissions of twelve 400-MHz LMR systems from various manufacturers in 2009. ITS engineers developed a proper measurement procedure and corresponding measurement system to study low-power, third-order harmonic emissions in the presence of the strong fundamental-frequency power. ITS coordinated with the National Institute of Standards and Technology (NIST) to use their anechoic chamber for these measurements. Figure 1 shows ITS engineers in the anechoic chamber.

Terminal Doppler Weather Radar Interference Investigation

In spring and summer 2009, field measurements were conducted to determine the cause of interference from certain DFS devices into an operational 5-GHz TDWR system. DFS is a method whereby Unlicensed National Information Infrastructure (U-NII) devices, which use the 5-GHz band for unlicensed operations, must detect the operations of radars and promptly vacate the channel if local radar signals are present. The significant effort required three rounds of measurements. The first occurred at a radar field site that was experiencing the interference (see Figure 2). Measurements from this radar provided initial insight into the interference sources and the interference mechanism. The second series of tests took place at the ITS laboratory, immediately following the operational field site measurements. These tests were performed in a controlled lab environment that allowed ITS engineers to thoroughly characterize the behavior and operation of numerous DFS devices in the presence of simulated TDWR signals. Private industry representatives participated in the lab tests to assist the ITS test team and observe the results. The final set of measurements took place at a Government test and development center. This set was also conducted in a controlled environment with participation from private industry engineers. It allowed ITS engineers to explore the interference mechanism further, characterize at what Interference-to-Noise (I/N) levels these interference artifacts manifest themselves, and develop solutions for improved protection of TDWR systems from DFS devices.

Figure 1. ITS engineers performing harmonic measurements on Land Mobile Radio systems in an anechoic chamber (photograph by J.R. Hoffman).

Figure 2. An ITS engineer performing rooftop measurements to study the electromagnetic compatibility between a weather radar and nearby wireless devices (photograph by J.E. Carroll).

DFS Measurement Capabilities

DFS devices are defined as U-NII devices that provide short-range, high-speed, wireless digital communications. In order to monitor the performance of the devices that are currently on the market, NTIA purchased three 5-GHz U-NII devices “off the shelf” and tested them against the published compliance standards adopted by the FCC in FY 2006. The results obtained to date have been reported to the FCC, and more of this type of testing is expected to occur in FY 2010.

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RSMS 4th Generation System Development

OUTPUTS

- A low frequency preselector and a YIG tracking system for frequencies below 3 GHz.
- Several new ITS custom-designed software modules for instrument control and measurement.
- Specialized measurement capabilities used for the Spectrum Sharing Innovation Test-Bed project.
- Exploration of an FPGA hardware system that can be incorporated into RSMS 4th generation software as a reconfigurable instrument.

OVERVIEW

The 4th generation system for Radio Spectrum Measurement Science (RSMS) 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 2009.

PRESELECTOR DEVELOPMENT

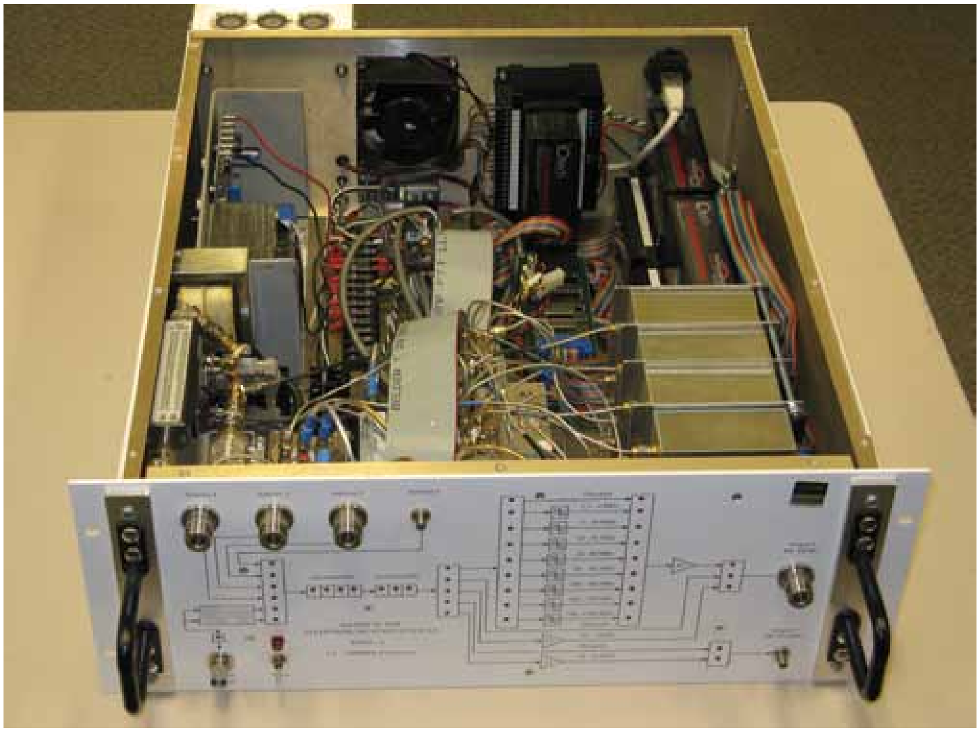
In support of the RSMS measurement system, ITS is developing customized preselector units, which filter unwanted signals and amplify the input to increase system sensitivity. Over the last year, two new capabilities were developed—a YIG tracking system for frequencies below 3 GHz and a low frequency preselector that operates between 10 – 1000 MHz. YIG filters are voltage-controlled tunable filters often used for preselection filtering during various spectrum measurements. Most spectrum analyzers have a frequency-tracking voltage output that can, with a little conditioning, directly control the YIG filter to track the frequencies measured by the spectrum analyzer. However, the spectrum analyzer ITS most commonly uses only provides a frequency tracking voltage above 3 GHz. As many measurements occur below 3 GHz, the RSMS 4th generation system needed the capability for YIG tracking during frequency-stepped and -swept measurements. Utilizing an arbitrary waveform generator, some external circuitry, and software, ITS designed, constructed, and verified for use a unique system for YIG control below 3 GHz.

ITS has completed the design and construction of the low-frequency (10 – 1000 MHz) preselector (see figure) and is currently developing software for testing and control. This software module will be integrated into the RSMS 4th generation software package, the anticipated time for completion being approximately three months into FY 2010. The purpose for this preselector is to provide amplification and dynamic attenuation for frequencies below 1 GHz, as well as to provide additional gain and attenuation to optimize sensitivity and dynamic range when used in conjunction with the higher frequency preselectors. This is one of the more challenging preselectors to design and construct because these higher frequencies (up to 28 GHz) necessitate careful construction to minimize losses and reflections.

SOFTWARE MODEL DEVELOPMENT

Over the 2009 fiscal year, ITS made several new additions and improvements to software measurement routines. This includes modifications to the amplitude probability distribution (APD) measurement routine, the stepped APD measurement routine, and the swept measurement routine. Improvements were made to the APD measurement program by including the addition of an event table, multiple timed acquisitions capability, and a data viewer that can plot individual plots or multiple plots on a graph which can further be saved as a MATLAB .fig file. The data is now saved in two formats, an ASCII file and a MATLAB .mat file. Modifications were made to the stepped APD measurement by adding an event table, event input form, and a data viewer.

The program is capable of performing APD analysis at designated steps along a range of frequencies. The measured data is also processed into max, mean, median, and minimum values for each frequency step, as well as a contour plot of multiple APDs. ITS modified the swept measurement routine to include capabilities for multiple sweeps with a specified time between sweeps. This routine can repeat the entire event table at specified intervals indefinitely, by a specified number of times, or by a specified



A low-frequency preselector (photograph by J.R. Hoffman).

period of time. A new MATLAB .mat file format has also been added to the existing file structure. Additional development in FY 2009 included an instrument software control module for one of our older (but frequently used) spectrum analyzers, as well as the inclusion of extra detection modes in an existing software control module used with another spectrum analyzer.

Spectrum Sharing Innovation Test-Bed

In order to help supplement the development of measurement capabilities used for the Spectrum Sharing Innovation Test-Bed project, ITS developed a fully automated measurement system for measuring radio signal detection and evacuation by Dynamic Spectrum Access (DSA) devices operating in land mobile radio (LMR) bands. This measurement required the acquisition and processing of tens of thousands of signal traces that necessitated the development of fully automated and flexible capabilities. In order to develop these capabilities, ITS made additional improvements and upgrades to three existing instrument software control modules—two different digital oscilloscope modules and a vector signal generator module. All of these capabilities were incorporated into the RSMS 4th generation software to expand its capabilities for performing this measurement, as well as other types of measurements.

FPGA Hardware System Research

Recent work has started exploring the possibility of a reconfigurable field programmable gate array (FPGA) hardware system that can be used for RSMS system control and high speed digital signal processing. It can serve as a reconfigurable instrument in which the interface control software can be incorporated into the RSMS 4th generation software for customized and unique signal processing, as well as control radio spectrum-related measurement systems like direction finding systems. Work this year entailed establishing a methodology of controlling FPGA designs from software running on a PC over an Ethernet connection to the FPGA. An example Visual Basic program was successfully developed to control an application on the device. The next step in this exploratory process will be to pass data to and from the FPGA chip.

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Table Mountain Research Program

OUTPUTS

- NOAA weather radio receiver performance testing and validation.
- Antenna characterization and radio propagation studies.
- Radar and LADAR research.

OVERVIEW

The Table Mountain Field Site and Radio Quiet Zone supports fundamental research into the nature, interaction, and evaluation of telecommunication devices, systems, and services. Activities this year have included:

ANTENNA CHARACTERIZATION AND RADIO PROPAGATION

ITS is developing a new propagation measurement system and signal processing methodology for performing high-resolution radio propagation measurements in both the time and frequency domain. Measurements have been performed in a frequency range of 20 MHz–6 GHz, as shown in Figures 1 and 2. The signal processing and measurement sequences remove the transmitting and receiving impulse responses. Range resolutions of 0.1 – 1.0 m have been realized in the tests performed so far.

Figure 1. Log-periodic receiving antenna used to perform field uniformity measurements of the Table Mountain turntable (photograph by R.T. Johnk).

Tests were performed at the Table Mountain facility to develop a radio-wave propagation model that could meet a unique set of requirements for use in scenarios with ultra-low antenna heights up to 3 meters, at frequencies of 150 – 6000 MHz, and at distances from 2 meters to 2 km. Data gathered from these tests are being used to support the development of new near-ground radio propagation models.

RADAR AND LADAR RESEARCH

The Table Mountain Field Site provides a large, open, unobstructed area that is ideal for the study of traditional radar as well as laser-based LADAR systems. ITS and industry researchers use the Table Mountain facility to validate new measurement methods and to test the operation and performance of new radar and LADAR systems. Some of the work this year has included: Bio-Aerosol detection, Synthetic Aperture LADAR, and long-range three-dimensional holographic imaging.

NOAA WEATHER RADIO TESTING

NOAA Weather Radio (NWR) provides continuous information of the latest weather conditions directly to the public from the National Weather Service offices, and per a 1975 White House policy statement, NWR was designated as the sole Government-operated radio system to provide warnings regarding natural disasters and nuclear attack directly into private homes. As an extension to this policy, NWS has expanded the role of NWR, in cooperation with the Federal Emergency Management Agency (FEMA) and the Federal Communications Commission (FCC), to include "all hazards."

ITS has developed simulated NWR broadcasts and a series of repeatable measurement methods to test the performance of these receivers. NOAA uses these test results to determine whether a manufacturer may use the NWR logo on their products. The compiled results of numerous tests also help NOAA determine the possible cause of receiver malfunctions reported by the public when units do not

Figure 2. Field uniformity transmission measurement with two log-periodic antennas 3.5 m above the Table Mountain turntable (photograph by R.T. Johnk).

respond during a weather event or other broadcast emergency.

Before applying to NOAA to use the NWR logo, individual NWR receiver manufacturers can enter into Cooperative Research and Development Agreements (CRADAs) with ITS to verify that their receivers meet the requirements and to make improvements where needed.

FY 2009 Cooperative Research and Development Partners

- Arete Associates
- Lockheed Martin/Coherent Technologies
- First RF Corporation
- University of Colorado, AUGNet
- Deep Space Exploration Society
- RF Metrics
- Symmetricom

Recent Publications

C. Dixon and E. Frew, "Maintaining optimal communication chains in robotic sensor networks using mobility control." Invited to special issue of *Mobile Networks and Applications (MONET)*, 14(3):281-291 Jun. 2009.

R. Howe, "DSES work on a research project for galaxy rotational Doppler shifts," *Proceedings of the Conference of the Society of Amateur Radio Astronomers*, ARRL, Newington, CT, 2009.

J. Riggs, "Comparing the distributions, specifically their connate parameters, resulting from the selected additive combinations of the real and imaginary components of the signal spectral density function," DSES, 2009. Available: http://deep-space.org/docs/aHalfRayComp.pdf

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Spectrum Sharing Innovation Test-Bed Pilot Program

Outputs

- Develop and build measurement systems for different catergories of measurements.
- Perform measurements that examine the feasibility of increased frequency sharing.

Overview

The National Telecommunications and Information Administration (NTIA), in coordination with the Federal Communications Commission (FCC) and other Federal agencies, established a Spectrum Sharing Innovation Test-Bed pilot program to examine the feasibility of increased spectrum sharing between Federal and non-Federal users. The program was an opportunity for the Federal agencies to work cooperatively with industry, researchers, and academia to objectively examine new technologies that can improve management of the nation's airwaves. ITS, on behalf of NTIA, performed laboratory measurements to characterize spectrum sharing devices that were provided by participants in the program.

On February 5, 2008, NTIA published a Notice in the Federal Register describing the Test-Bed program.[1] The program evaluated the ability of Dynamic Spectrum Access (DSA) devices employing spectrum sensing and/or geo-location techniques to share spectrum with land mobile radio (LMR) systems operating in the 410 – 420 MHz Federal band and in the 470 – 512 MHz non-Federal band. DSA technology allows a radio device to:

1. Evaluate its radio frequency environment using spectrum sensing, geo-location, or a combination of spectrum sensing and geo-location techniques.
2. Determine which frequencies are available for use on a non-interference basis.
3. Reconfigure itself to operate on the identified frequencies.

Test-Bed Plan Development

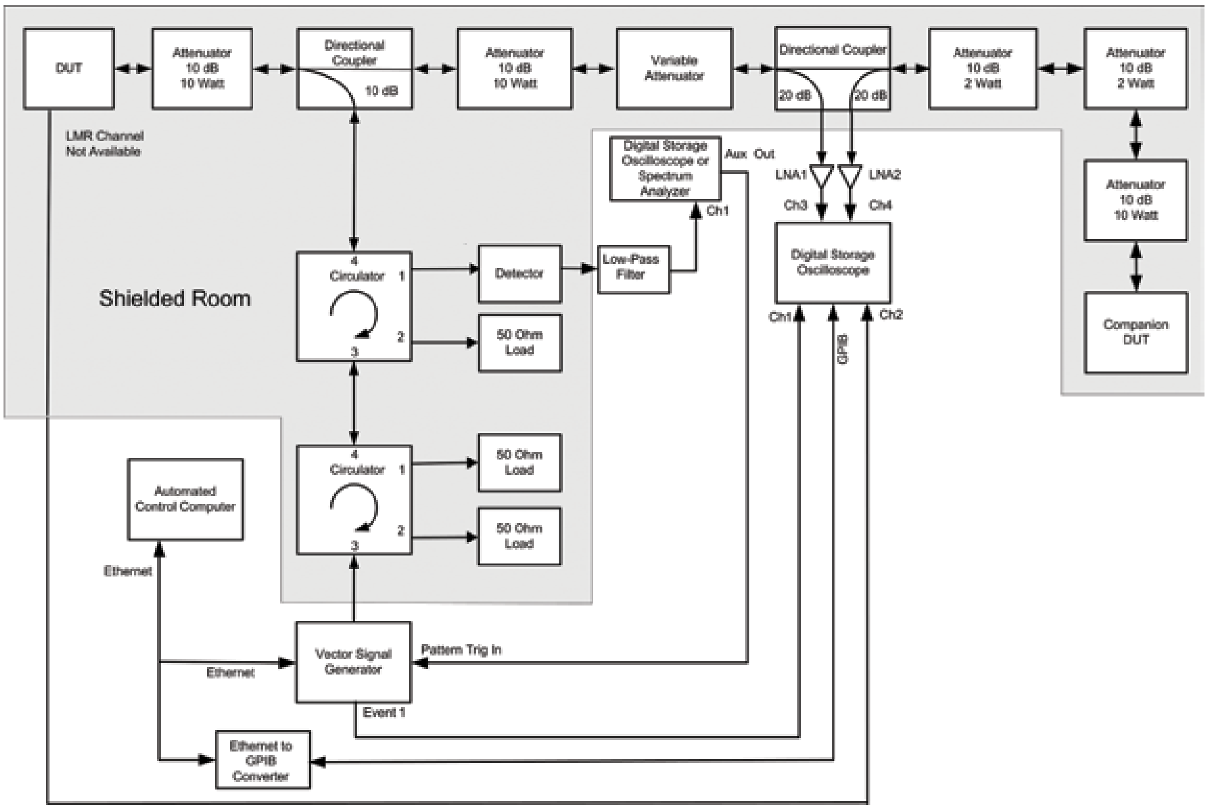
ITS participated in developing a test plan that describes the Test-Bed laboratory measurements which was published at the NTIA website.[2] The measurements that ITS performed in FY 2009 can be grouped into five categories. The first category was Emission Characterization. In this category, spectral emissions of the DSA device were measured as the device modulation, transmission size, power level, and transmission mode were varied to capture the range of spectra that the device can generate. This resulted in over 100 measurements. Samples of the device transmissions were recorded and examined to understand the time domain characteristics.

The second category was Sensor Characterization. These tests were designed to assess the DSA's capability to sense an LMR incumbent signal. The sensitivity of the DSA's detector was measured as it was exposed to faded and non-faded LMR signals. This involved making hundreds of measurements and processing the data to extract key parameters of interest such as "probability of detection" and the "time to evacuate" an LMR channel. The figure shows a block diagram for one of the tests. An LMR signal is created in the Vector Signal Generator and sent to the device under test, which is a DSA device. The power level from the Vector Signal Generator is varied to measure the detector sensitivity. An oscilloscope monitors the transmissions (to measure the "time to evacuate") from both DSA devices (which are communicating with each other) through a directional coupler.

The third category was Geo-Location Characterization. Some DSA devices implement a policy database which contains information about the frequencies that can or cannot be used within a defined geographical area. The device has the ability to decide if it is within a geographical area either by the use of a GPS receiver or operator input. One test determined the ability of the DSA to recognize that it has a current (not expired) geo-location policy database before making any transmissions. Another test examined the DSA behavior when it lost the

1. Spectrum Sharing Test-Bed, Notice of Solicitation of Participation, 73 FR 6710 (Feb. 5, 2008)

2. http://www.ntia.doc.gov/frnotices/2006/spectrumshare/Phase_I_Test_Plan_Final_Version_NTIA_Website.pdf



A block diagram of one of the Sensor Characterization tests.

ability to determine where it was located. The time to cease transmissions was measured when the position information was unavailable.

The fourth category was Spectrum Access Behavior. The ability of the geo-location equipped DSA to properly transmit on available LMR channels and avoid transmitting on locked-out LMR channels based on geographic location was tested. The device was moved into and out of a defined geographical area while its transmissions were monitored.

The fifth category was LMR Emission Characterization. The spectral emissions of two LMR transmitters were measured using a standard transmit test pattern as the modulation source. Samples of the device transmissions were recorded and examined to understand the time domain characteristics.

The devices that are provided by the participants have different approaches which exercise various ideas for spectrum sharing. Several different types of radio technologies are implemented in the devices resulting in each device offering different advantages. The Test-Bed program measurements will quantify some of the radio technologies and provide a view of the performance of the spectrum sharing technologies.

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Radio Noise and Spectrum Occupancy Measurement Research

Outputs

- Development of an automated, swept spectrum measurement capability for frequencies between 100 MHz and 1100 MHz.
- Spectrum measurements from 104 MHz to 1060 MHz in residential and urban environments in the Boulder/Denver area.
- Wideband and narrowband noise measurements at 112.5, 221.5, and 401 MHz in residential and urban environments in the Boulder/Denver area.

Overview

Proper radio communication system design requires, among other considerations, knowledge of the noise and interference environment at the receiving location. While distinguishing between (what is considered) noise and (what is considered) interference is subject to different interpretations, one interpretation is that interference arises from intentionally radiated signals, whereas noise arises either from natural sources or from unintentionally radiated signals generated by man-made sources. Noise can be further categorized as being either internal to the receiving system or external to the receiving antenna.

External, man-made noise was studied extensively in the 1960s and 1970s and culminated in the development of a man-made noise model that is still in use today (see Recommendation ITU-R P.372-10). However, there are many reasons to suspect that the man-made radio noise environment may have changed since the 1970s. Potential factors include the introduction of new technologies such as computers, cellular telephones, and other electronic devices; increases in spectrum crowding; the use of RF overlay technologies; the aging power distribution infrastructure; and improvements in auto ignition systems. Because of all these factors, there has been a renewed, worldwide interest in measuring, quantifying, and modeling man-made radio noise.

Spectrum Measurement System

Continuing to address this interest, ITS' ultimate goal in FY 2009 was to perform noise measurements at three different frequencies below 1 GHz

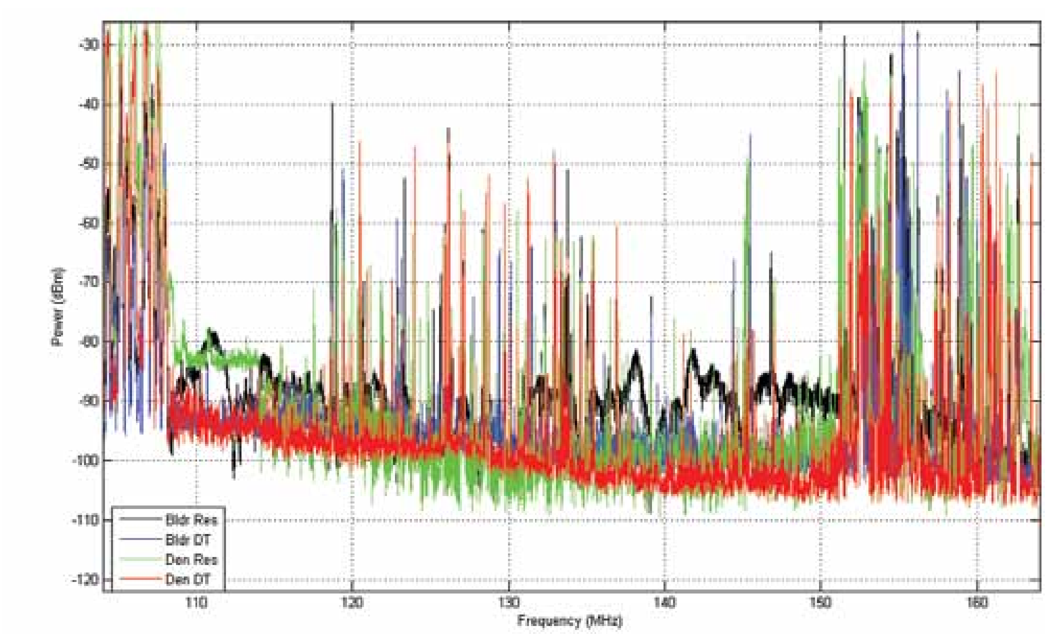

Figure 1. Maximum received signal power for 104 MHz to 164 MHz for all four measurement locations.

in representative residential and urban locations. To achieve this goal, appropriate frequencies at which to perform the noise measurements needed to be determined, which required a spectrum survey of the radio environment at proposed noise measurement sites (a residential and urban location in Boulder and a residential and urban location in Denver). Therefore, our initial work in FY 2009 involved developing an automated, swept spectrum measurement capability for frequencies between 100 MHz and 1100 MHz.

Figure 2. View of the noise measurement system antenna and operating environment for measurements conducted in the urban location in downtown Denver, Colorado (photograph by G. Sanders).

ITS developed a measurement system that consisted of two omnidirectional, discone antennas; an ITS-designed software controlled RF antenna switch; and a legacy, commercial, off-the-shelf RF preselector and spectrum analyzer. Modifications to the ITS RSMS-4G software were implemented to provide computer control of the measurement system. The system was designed to perform automated measurements from 104 MHz to 1060 MHz. One discone antenna was used for frequencies below 200 MHz while the other was used for the higher frequencies. The appropriate antenna is automatically used when the measurement system is operating depending on the current measurement frequency.

Spectrum Measurements

Spectrum measurements were performed using this system at one residential and one urban location in Boulder, Colorado and at one residential and one urban location in Denver, Colorado. ITS collected received signal power data as a function of frequency over fifteen frequency sub-bands from 104 MHz to 1060 MHz. The data were processed to provide maximum, mean, and median received signal power vs. frequency for all four locations. Figure 1 shows an example plot of maximum received signal power for 104 MHz to 164 MHz for all four measurement locations.

The received signal power vs. frequency data were analyzed to determine optimal frequencies at which to conduct the noise measurements. The selection of optimal frequencies included the consideration of the number and power levels of signals both within and adjacent to a 1-MHz bandwidth (bandwidth used for the wideband noise measurements). Consideration was also given to the type of licensed transmitters both within and outside of the 1-MHz bandwidth. The goal was to identify areas in the spectrum with the minimum number and power level of intentional signals. Ideally, the selection of three frequencies would be spaced roughly an octave apart.

Noise Measurements

Based upon the results of the spectrum measurement data analysis, noise measurement frequencies of 112.5 MHz, 221.5 MHz, and 401 MHz were selected. Noise measurements were conducted at all three frequencies in the same measurement locations as the spectrum measurements. The measurements used the newly developed, automated wideband noise measurement system housed in the RSMS-4G measurement vehicle. For each frequency, ITS used a low insertion loss, highly-selective, fixed bandpass filter along with a quarter-wave monopole antenna mounted on a ground plane. At each location and frequency, six million I and Q noise data samples were collected in both a 1-MHz and 30-kHz bandwidth every 10 minutes for a duration of 24 hours. Figure 2 shows the noise measurement system antenna and the operating environment for measurements conducted in the urban location in downtown Denver, Colorado. Future work in this area will include analyzing the collected noise measurement data and publishing the results.

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Visiting ITS' video and audio labs, Commerce Secretary Gary Locke (center) learns from Jeff Bratcher how first responder safety equipment is accounted for in voice communications research (photograph by J. Burrus).

At ITS' audio labs, D.J. Atkinson affixes a fire fighter's self-contained breathing apparatus (SCBA) mask to an ITU-Standard Head and Torso Simulator for a video by the Association of Public Safety Communications Officials—International (photograph by B. Ingram).

ITS launched a website (www.pscr.gov) for the PSCR program, a joint effort between ITS and NIST/OLES (see facing page), which provides research, development, testing, and evaluation to foster nationwide public safety communications interoperability.

An ITS video camera records an exercise burn. Incident controllers can use video to analyze a fire based on smoke color and density, as well as flame intensity (photograph by D.J. Atkinson).

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 includes planning and analyzing existing, new, and proposed telecommunications and information technology systems, especially networks, to improve efficiency and enhance performance and reliability. ITS performs this work, commonly referred to as systems engineering, for both wireline and wireless applications.

This division conducts all phases of strategic and tactical planning as well as problem solving and actual engineering implementation. ITS engineers identify users' functional requirements and translate them into technical specifications. In the process, telecommunication system designs, network services, access technologies, and information technologies are all analyzed. A key event that occurred in FY 2009 was the formal branding of the Public Safety Communications Research (PSCR) program. This is a joint effort between ITS and the NIST Office of Law Enforcement Standards (NIST/OLES). The program performs research, development, testing, and evaluation to foster nationwide public safety communications interoperability.

Following is a summary of significant activities that occurred in the area of telecommunications and IT planning during FY 2009.

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Areas of Emphasis

Public Safety Communications Research One of the largest programs at the Institute, the PSCR program conducts broad based technical efforts aimed at facilitating communications interoperability and information-sharing among wireless and IT systems within the public safety community. This program is a joint effort with the National Institute of Standards and Technology's Office of Law Enforcement Standards. The sponsors of the research are the Department of Homeland Security and the Department of Justice. The research projects are planned and performed with coordination among local, State, tribal, and Federal practitioners. Technical thrusts within the program, described in separate sections on the following pages, include:

- Project 25 Standards Development
- Project 25 Compliance Assessment Program
- Public Safety Audio Quality
- Public Safety Interoperability Test Tools

Emergency Telecommunications Service (ETS) Standards Development The Institute develops and verifies ETS Recommendations for ITU-T Study Group 9. The project is funded by the Department of Homeland Security's National Communications System.

Multimedia Quality Research The Institute characterizes and analyzes the fundamental aspects of multimedia quality assessment. A primary goal of this research is to develop an algorithmic system to objectively assess multimedia quality by combining audio quality, video quality, and audiovisual synchronization information. This research is funded by NTIA.

Wireless Network Measurement Methods The Institute studies the performance characteristics of wireless networks and attempts to standardize measurement methods in order to better understand the applicability of different types of wireless networks to specific user requirements. This research is funded by NTIA.

Project 25 Standards Development

Outputs

- Leadership roles and formal participation to promote public safety interests in achieving P25 goals.
- Technical proposals to accelerate the development of P25 standards satisfying public safety requirements.
- User outreach to increase practitioner involvement in the P25 process and the adoption of P25 standards.

Overview

The overall goal of Project 25 (P25) is to enable and promote the development and use of interoperable Land Mobile Radio (LMR) equipment and systems that cost-effectively meet the complex and evolving mission-critical radio communication needs of the public safety community. Project 25 was established in 1989 by governmental entities and the Association of Public-Safety Communications Officials – International (APCO) for the primary purpose of realizing the benefits of digital narrowband LMR technologies for public safety practitioners and other users. To accomplish this vital goal, public safety, government, and manufacturer representatives participating in the P25 process develop, as a public-private partnership, voluntary consensus standards under the support of the American National Standards Institute (ANSI)-accredited Telecommunications Industry Association (TIA).

APCO Project 25 is unique in that it is an open, user-driven standardization process, with technical and operational requirements established through the participation of its stakeholders. The standards published by TIA establish the basis upon which:

- Manufacturers develop, implement, and offer P25 equipment and systems.
- Recognized laboratories conduct P25 compliance testing.
- Users specify, procure, and operate P25 radios and communications infrastructure.

The deployment of P25 equipment and systems continues to grow, with broad adoption by the more than 50,000 public safety organizations in the U.S. and by public safety organizations in over 54 countries.

Recent Congressional legislative and related actions have recognized P25 standardization as the preferred solution for narrowband LMR public safety users. Congress has identified several key P25-defined open interfaces as critical for near-term completion, including two of particular importance: the Inter-RF Subsystem Interface (ISSI) and the Common Air Interface (CAI). The ISSI and CAI are the most important P25 interfaces because they enable multi-agency interoperability involving use of multi-manufacturer P25 radios and P25 infrastructures, including across large geographic areas covering different public safety jurisdictions.

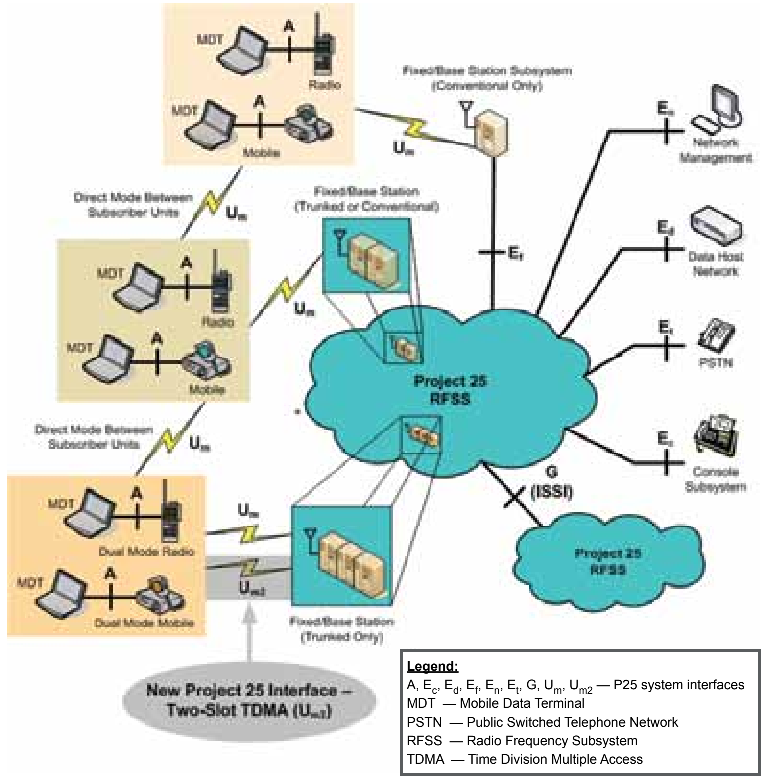
ITS' Involvement

ITS began to advance the development of Project 25 requirements and standards shortly after P25 was established. ITS continues, under the sponsorship of NIST/OLES, to support the accelerated development of P25 standards to meet increasing needs for functionally enhanced, compliant equipment and systems, and to satisfy Congressional mandates. Additionally, ITS' P25 standards development support efforts are an integral part of the recently established Public Safety Communications Research (PSCR) program, a joint effort of NIST/OLES and ITS. During FY 2009, ITS involvement, which provided technical and organizational representation for the sponsor, directly assisted the approval of new and revised P25 requirements and standards in several critical areas, including the ISSI and CAI, and in related areas of emphasis, including public safety audio quality research and the P25 Compliance Assessment Program.

ISSI Interoperability Test Standards

ITS technical efforts strongly contributed to the accelerated development and approval of P25 standardized tests for assessing the interoperability of equipment that implements P25 trunked voice services using the ISSI. The technical basis of these tests involves configuration and use of P25 radios connected to P25 Radio Frequency Subsystems (RFSSs) via the P25 CAI. The P25 RFSSs are interconnected using the ISSI to compose a P25 infrastructure. RFSS equipment passing these tests demonstrates that the ISSI has been implemented in an interoperable manner. Eleven test suites consisting of approximately 40 test cases are defined in the applicable standard, approved in July 2009 as

TIA-102.CACD. These tests have been included in the initial version of the ISSI recommended compliance assessment tests document, approved in August 2009 as TSB-102.CBBK. In addition, ITS contributed technical expertise to the development of an important addendum to an existing standard that defines test configurations for interoperability testing of wide-area, roaming P25 radios for voice operation in P25 trunked systems, approved in July 2009 as TIA-102.CABC-A-1.



Representative P25 Phase 2 System Model illustrating support of the new P25 Two-Slot TDMA CAI (U_{m2}).

Next Generation P25 CAI Standards

Another example of ITS' P25 involvement during FY 2009 is a series of contributions to the development of the next generation ("Phase 2") P25 CAI, the Two-Slot Time Division Multiple Access (TDMA) Standard. The P25 Two-Slot TDMA standard is urgently needed to satisfy regulatory and user requirements for more efficient use of limited radio spectrum. ITS contributions directly supported completion of the P25 Phase 2 Two-Slot Time Division Multiple Access (TDMA) Physical Layer Protocol Specification, published in July 2009 as TIA-102.BBAB, and the P25 Phase 2 Two-Slot TDMA Overview document, approved in August 2009 as TSB-102.BBAA. The new P25 CAI, shown in the figure as U_{m2}, provides 6.25 kHz channel-equivalent voice and data operation. Largely because of regulatory and system efficiency considerations, both manufacturers and users are planning on rapid adoption of P25 Two-Slot TDMA equipment and systems in the near-term. The suite of P25 Two-Slot TDMA standards are being developed consistent with user needs specified in the P25 Statement of Requirements (P25 SoR).

Leadership and Participation

ITS leadership in the P25 User Needs Subcommittee (P25 UNS) drove the development and approval of an updated P25 SoR in October 2008 and again in August 2009 to meet evolving user requirements on a timely basis. At the request of the P25 Steering Committee, an ITS staff member acted as convener for the P25 UNS on an interim basis from December 2008 to August 2009. Throughout FY 2009, an ITS staff member acted as Editor of the P25 SoR, a role that ITS staff has performed since 2005 at the request of the P25 Steering Committee.

Formal participation in the P25 process continued throughout FY 2009, with the submittal of numerous letter ballot comments enabling standards to be approved consistent with ITS and sponsor objectives. Accelerated completion of key P25 standards continued in 2009, including the publication of twenty-one standards associated with the ISSI and other critical P25 interfaces. ITS staff continues to conduct important outreach activities; for example, enhancing the P25 Document Suite Reference (P25 DSR) as part of the PSCR program (http://www.pscr.gov/outreach/p25dsr/p25dsr.php).

In FY 2010, ITS will continue to support the accelerated development of key Project 25 requirements and standards to further realize interoperable narrowband LMR equipment and systems that satisfy the mission-critical communication needs of the public safety community.

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Project 25 Compliance Assessment Program

Outputs

- Development of technical materials for DHS P25 CAP Governing Board.
- Grant guidance language for Federal Project 25 equipment grant programs.
- Laboratory assessment program management and subject matter expertise.
- Compliance assessment related Project 25 standards.

Overview

Historically, public safety agencies have purchased and used equipment that was made by different manufacturers with inconsistent manufacturing practices and using different spectra. As a result of these inconsistencies, this equipment could not interoperate, preventing many public safety agencies from communicating when lives were in danger. Public safety organizations and the communications industry have partnered through Project 25 (P25) to eliminate these issues by developing standards that allow radios and other components to easily interoperate regardless of manufacturer. The goal of P25 is to specify formal standards for interfaces between the various components of a land mobile radio (LMR) system, commonly used by emergency responders.

After years of effort, industry was successfully incorporating standards into much of the radio and communications equipment used by public safety. However, preliminary test data indicated that some radios sold under the P25 label did not meet all of the standards' requirements. The problem was the lack of a reliable method to verify equipment compliance with P25 standards. "Testing was something that, for a long time, public safety assumed occurred, but then they realized that their toasters were tested to a higher degree than their radio systems," says Dereck Orr, National Institute of Standards and Technology/Office of Law Enforcement Standards (NIST/OLES) Communications Program Manager.

In 2008, to address this issue, ITS worked with NIST/OLES and the Department of Homeland Security's Office of Interoperability and Compatibility (DHS OIC) to build an independent coalition of public safety users and communications equipment manufacturers to create the P25 Compliance Assessment Program (CAP) to test the equipment for standards compliance.

Program Structure

The P25 CAP is a voluntary program that allows P25 equipment suppliers to formally demonstrate their products' compliance with a select group of requirements within the P25 suite of standards. The purpose of the program is to provide emergency response agencies with evidence that their communications equipment meets P25 standards for performance, conformance, and interoperability.

The program requires test laboratories to demonstrate their competence through a rigorous and objective assessment process. Such a process promotes the user community's confidence in, and acceptance of, test results from recognized laboratories. All equipment suppliers that participate in the P25 CAP must use recognized laboratories to conduct performance, conformance, and interoperability tests. P25 equipment suppliers release summary test reports from recognized labs along with declarations of compliance. This documentation will serve to increase the public's confidence in the performance, conformance, and interoperability of P25 equipment. Further, the declaration of compliance-related documents developed by program participants will provide useful technical information about the equipment.

Performance, conformance, and interoperability issues are likely to occur in all communications technologies and especially in those, like P25, with protocols that constantly adapt to changing user requirements. Such problems should be resolved within the P25 CAP, and, notably, before product launch and deployment.

In short, the P25 Compliance Assessment Program:

- Was mandated by Congress in legislation.
- Is a cost effective solution. ITS is supporting NIST/OLES and DHS OIC in the recognition of independent laboratories to conduct the testing rather than building a large centralized facility.
- Is a voluntary program that allows P25 equipment suppliers to formally demonstrate their products' compliance with a select group of requirements.

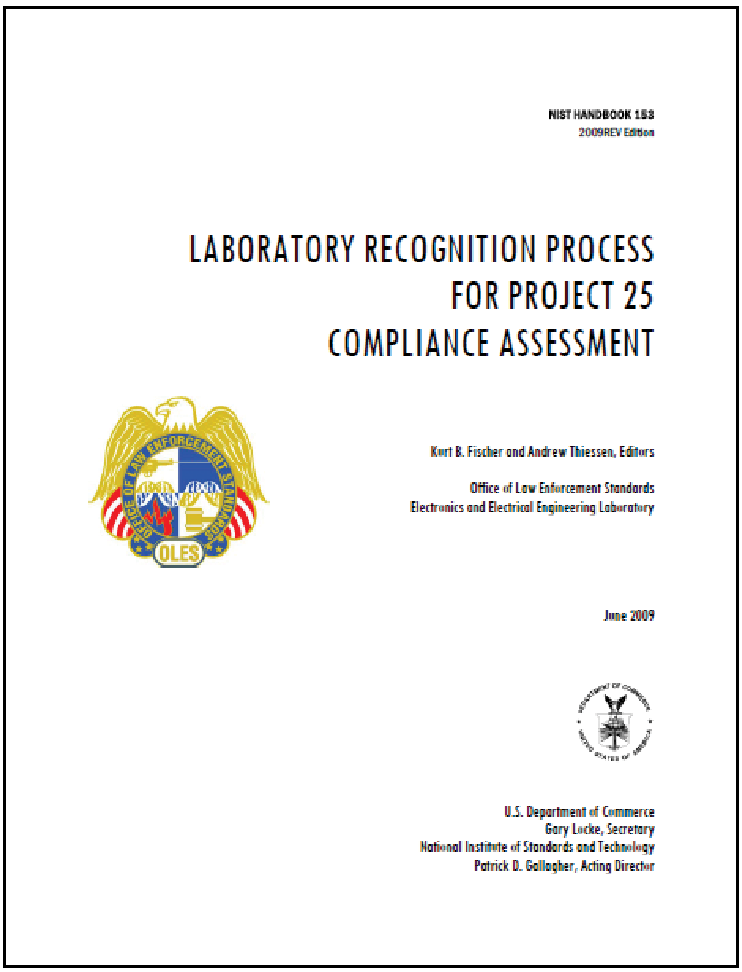
- Is a partnership of ITS, DHS OIC, NIST/OLES, industry, and the emergency response community.
- Was launched in 2008 with eight laboratories recognized in May 2009.
- Is an example of government making a minimal investment that catalyzes industry and the community it serves to develop a solution that will affect billions of dollars in purchases.

Results

The P25 CAP is providing more than 60,000 emergency response agencies nationwide with a consistent and tractable perspective of P25 product compliance. It also provides a means of verifying that billions of Federal grant dollars and Federal procurements of LMR systems are being invested in standardized solutions and equipment that promotes interoperability.

A number of important milestones were reached in FY 2009:

- The P25 CAP Governing Board met many times, and many critical requirements documents have been released, including the Testing Requirements, Supplier's Declaration of Compliance Requirements, Summary Test Report Requirements, and several revisions to the NIST Handbook 153. ITS drafted all of the documents currently approved.
- The laboratory assessment process was begun in FY 2009, where ITS provided subject matter experts for the process, as well as leadership in the form of the P25 CAP Laboratory Program Manager and Quality Manager. Eight laboratories were recognized by DHS on May 4, 2009.
- ITS continues to work within the standards development process of TIA to ensure timely release of standards that directly impact the P25 CAP, namely test standards for the Common Air Interface and the Inter-RF Sub-System Interface.
- ITS assisted in developing Federal grant guidance language for DHS that affects how Federal grant money is used by state and local public safety in the purchase of communications equipment.


NIST HANDBOOK 153
2009REV Edition

LABORATORY RECOGNITION PROCESS
FOR PROJECT 25
COMPLIANCE ASSESSMENT

Kurt B. Fischer and Andrew Thiessen, Editors

Office of Law Enforcement Standards
Electronics and Electrical Engineering Laboratory

June 2009

U.S. Department of Commerce
Gary Locke, Secretary
National Institute of Standards and Technology
Patrick D. Gallagher, Acting Director

Cover of the NIST Handbook drafted by NIST/OLES and ITS.

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Public Safety Audio Quality

OUTPUTS

- Technical reports describing experimental conduct and results.
- Contributions to standards bodies regarding measurement methods for public safety audio quality.

OVERVIEW

Public safety workers frequently operate in some of the harshest and most dangerous conditions. The ability to communicate warnings and distress calls is essential when a public safety practitioner's life is in danger. However, common background noises in the public safety environment, such as sirens, chain saws, and personal alert safety systems (PASS), can interfere with those essential communications. This interference can be so severe that it can prevent a practitioner and the person talking with him or her from understanding each other at the most critical moments.

To increase communication efficiency even in the worst conditions, manufacturers need to understand how background noise affects voice communications to determine what technology improvements are needed to overcome any background noise issues. ITS and its program sponsors (NIST's Office of Law Enforcement Standards and the Department of Homeland Security's Office of Interoperability and Compatibility) are addressing this issue by developing and implementing tests that measure how digital radios operate in the presence of loud background noise.

The Public Safety Audio Quality project takes an innovative approach to addressing the needs of the public safety community. Working directly with practitioner agencies, the project conducts both field and laboratory studies to increase the awareness of public safety requirements, conduct experiments that reflect the real environment in which public safety must operate, and quantify potential communications technology issues and identify solutions for those issues.

FIELD & LABORATORY STUDIES

The field studies conducted by the project are essential to understand the environments in which public safety practitioners must operate (Figure 1). To date, field measurements and recordings have been made in a variety of public safety vehicles, and at several fire scenes to provide information specific to noises encountered by the fire service. These field studies provide information on radio usage, operational environment, and common practices of public safety personnel. Typically, these field studies will involve two types of recordings. The first is recordings of overall operation that help increase understanding and comprehension of public safety operational requirements. The second type of recording is a high-quality digital recording of specific environmental noises that can be shared with the community and be used in laboratory experiments.

The high-quality digital recordings (Figure 2) are used to reproduce real-life sound levels inside a sound attenuated chamber that contains an ITU-Standard Head and Torso Simulator (HATS). The HATS has a calibrated speaker representing the mouth

Figure 1. Field equipment recording audio from radio channels as well as microphones embedded in a burning house (photograph by D.J. Atkinson).

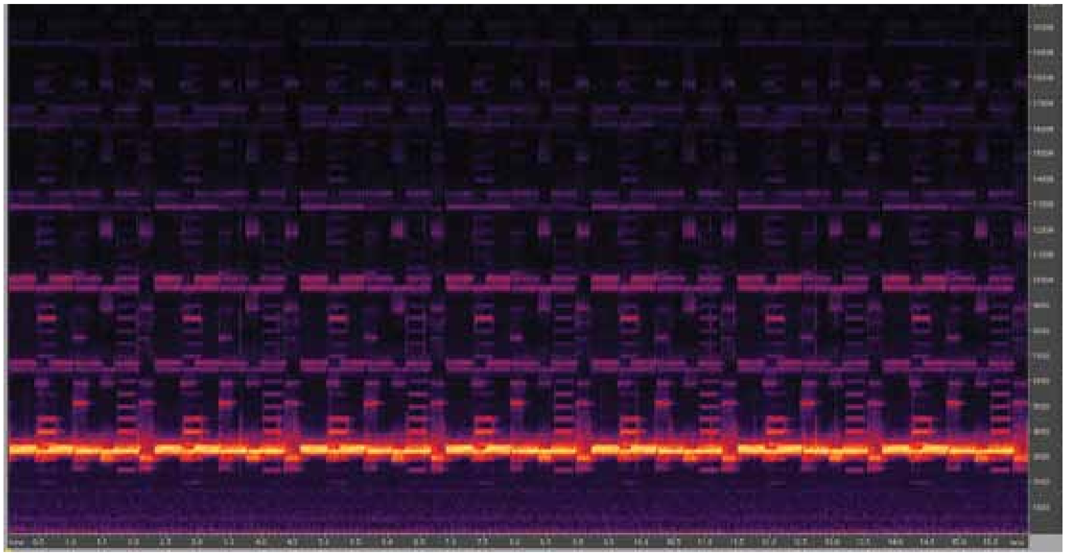

Figure 2. This spectrogram shows active frequencies in Hertz versus time in seconds for a high quality recording of two PASS alarms sounding.

and a calibrated microphone representing each ear, enabling the HATS to simulate a conversation in any noise environment for which a recording exists. Utilizing a pair of these HATS each in their own chamber enables both halves of a conversation to be simulated and recorded for later analysis or playback to a subjective listener panel.

In a previous subjective experiment, various fire-specific noises were mixed with audio to perform an intelligibility test. The noises included such sounds as a chain saw, a fire-hose fog nozzle, a low air alarm from breathing apparatus, and a personal alert safety system (PASS) alarm. The experiment compared the intelligibility of digital and analog radio communication systems in the presence of such noises. Results were published in an NTIA Report[1] and companion recommendations published by the International Association of Fire Chiefs.[2]

Audio Performance Working Group

Based on that intelligibility test, the Project 25 standards committee created the Audio Performance Working Group (APWG) to further quantify these issues. The APWG is looking at the issue from a systems perspective where making many small improvements throughout the system can improve the quality at the output. To further this work, the APWG has spent most of FY 2009 developing a follow-on subjective test with four goals in mind:

- Test the impact of the IAFC recommendations to see how they improve audio performance.
- Test an updated release of the vocoder software to evaluate improvements on that front.
- Incorporate radio channel impairments in the tests to help understand the compounding effect that multiple impairments will have on communications.
- Use reference implementations of the radio systems to provide a baseline performance that can be applied across manufacturers.

In FY 2010, the project will conduct tests and publish results that will enable the identification of strategies and technologies that can improve the intelligibility of digital radio systems in the presence of loud background noises. The work will continue to involve the IAFC and the Project 25 communities.

1. D. Atikinson and A. Catellier, "Intelligibility of selected radio systems in the presence of fireground noise: test plan and results," NTIA Technical Report TR-08-453, Jun. 2008. http://www.its.bldrdoc.gov/pub/ntia-rpt/08-453/

2. IAFC Digital Problem Working Group, "Interim report and recommendations: fireground noise and digital radio transmissions," International Association of Fire Chiefs, Jun. 2008. http://www.iafc.org/digitalproject/

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Public Safety Interoperability Test Tools

Outputs

- An ISSI reference implementation.
- Software capable of conformance and performance testing the ISSI protocol.
- Software capable of performance testing the CSSI protocol.

Overview

The Project 25 (P25) suite of standards is necessary to ensure interoperability among the different levels of government and between different vendors. Out of the seven P25 interfaces, Congress considers completing the Inter-RF Sub-System Interface (ISSI) to be top priority.

Essentially, the ISSI is a network protocol that operates over standard network interface cards (NIC). This interface is intended to be present in future deployments of P25 Radio Frequency Sub-Systems (RFSS) so that the ISSIs of different RFSSs can be inter-connected using various media (Ethernet being one example).When the ISSIs of various RFSSs are interconnected, IP packets that contain IMBE encoded voice can be transmitted and received.

The ISSI is important to public safety agencies because it will foster competition among RFSS manufacturers. This increased competition will lower P25 infrastructure costs. Most importantly, the ISSI will promote interoperability between the different vendors who manufacture RFSSs, allowing consumers to implement P25 communications networks using RFSSs from multiple vendors.

The ISSI conformance test document (TIA-102.CACC) was published in January 2009. These conformance tests help to verify that vendor implementations conform to what has been specified in the P25 ISSI Messages and Procedures for Voice Services (TIA-102.BACA).

Testing the ISSI

In order to objectively verify that a vendor conforms to TIA-102.BACA, ITS, in conjunction with NIST, has developed ISSI Test Tools (ITT) as a reference implementation of the ISSI protocol stack. Since ITT has been implemented in Java, the software can be loaded on a regular desktop PC that has a Linux or Windows operating system on it. A single instance of ITT is capable of emulating one of four different roles in a P25 ISSI based network:

- calling serving RFSS
- calling home RFSS,
- called home RFSS, and
- called serving RFSS.

Ideally, ITT will be placed in a test configuration, as defined in the conformance test document, which will fulfill one of the four roles depending on the test case under consideration. The number of vendor RFSSs and roles may vary depending on the test case requirements. It is also possible and more common to test in isolation the ISSI of a single vendor RFSS. This is the preferred configuration when attempting to determine a particular vendor's conformance. This scenario implies that there is only one vendor RFSS with a real ISSI and the rest of the ISSI interfaces are emulated by ITT (Figure 2). The number of emulated ISSIs and the role of the emulated interfaces will vary depending on the conformance test case. Since ITT does not currently have the capability to emulate the P25 common air interface, the behaviors of (or events generated by) subscriber units are emulated in the ITT software.

From the ITT GUI, the user can select a conformance test case to execute. After the test case has completed execution, the user can then view the SIP and RTP Push-to-Talk (PTT) messages that were exchanged between ISSIs in a graphical message sequence chart (MSC) (Figure 2 and Figure 3).

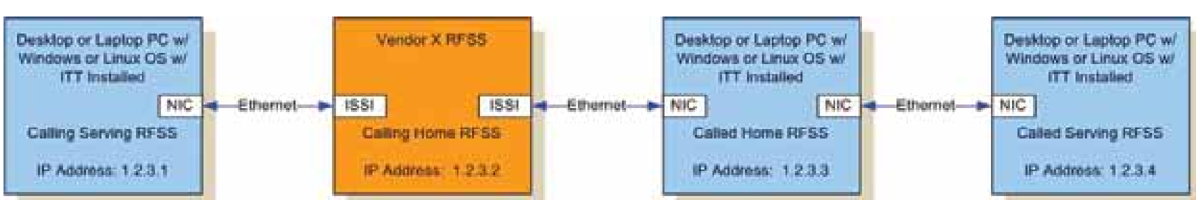

Figure 1. Test architecture with three instances of ITT. Note that IP addresses are for example purposes only.

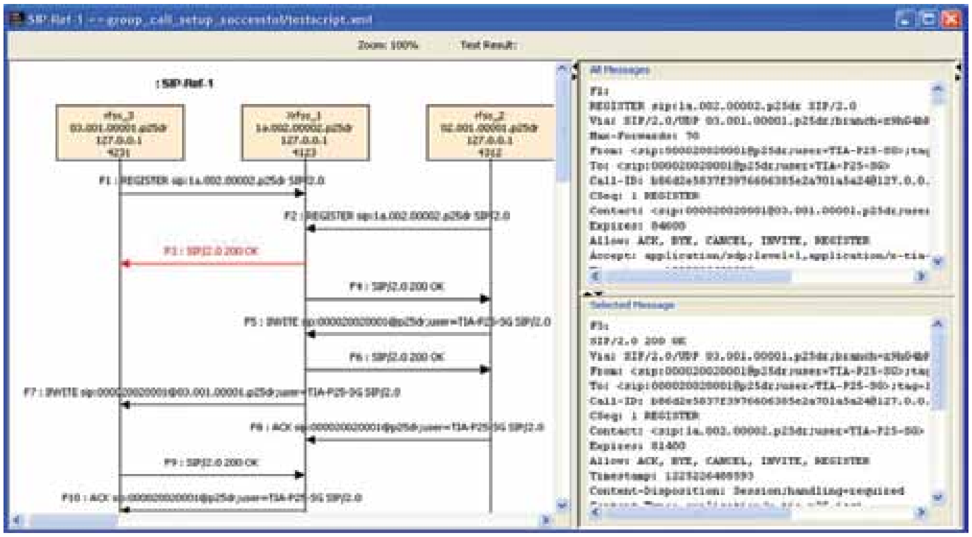

Figure 2. SIP MSC for Test Case 9.1.1 - Unconfirmed Group Call Successful.

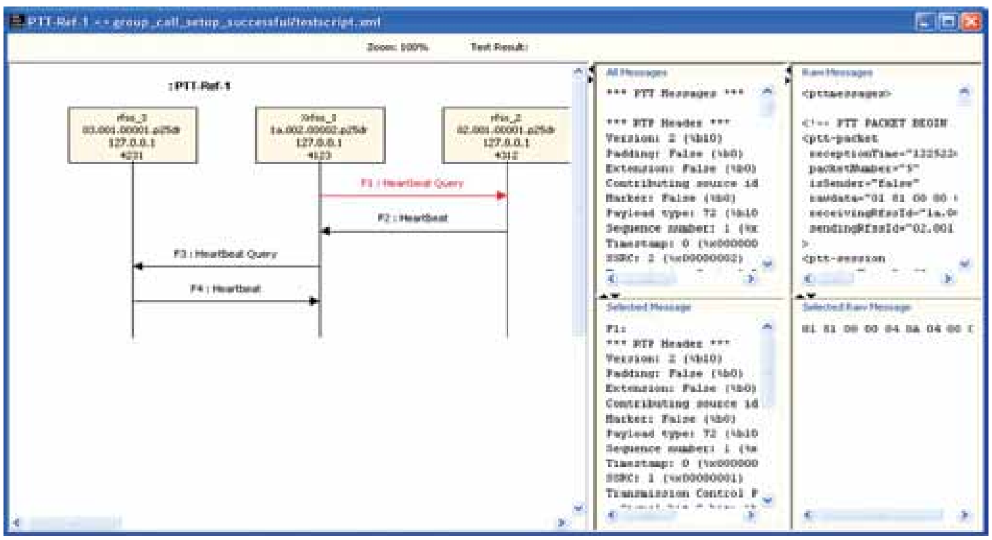

Figure 3. RTP PTT MSC for Test Case 9.1.1 – Unconfirmed Group Call Successful.

When the test case has finished executing, ITT will automatically declare either pass or fail.

Raw IP packet data can be rendered by clicking on the message of interest in the MSC. The ITT has a packet processing capability that will generate an MSC based on the PCAP file that is fed in for processing. Wireshark is used in conjunction with ITT's packet processing capability to capture the messaging that occurs between all ISSIs (emulated or real) involved in a test and render the results in an easy-to-read MSC.

In FY 2009, ITT was expanded to test the performance of the ISSI according to the Project 25 ISSI Measurement Methods for Voice Services (TIA-102.CACA) standard, and it also was expanded to test the performance of the trunked CSSI (Console Sub-System Interface) according to TIA-102.CACA —Addendum 1. The primary purpose of a CSSI is to enable the connectivity of a dispatcher's console to an RFSS's CSSI. The CSSI is very similar to the ISSI with minor variations. To obtain the ITT software, visit https://p25-wireline.dev.java.net/.

Plans for FY 2010 include completing the validation of ISSI conformance test cases contained in ITT, validation of the ISSI performance test case engine, and validation of the CSSI performance test case engine.

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Emergency Telecommunications Service Standards Development

Outputs

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

Overview

In the aftermath of the 2001 terrorist attacks, the Federal Government is supporting ways to give priority treatment to emergency communications. Historically, the Government Emergency Telecommunications Service (GETS) has served emergency workers well for many years, but it is limited to the Public Switched Telephone Network (PSTN) in the United States. The Emergency Telecommunications Service (ETS) is a proposed solution that will function similarly to GETS. ETS will better serve emergency workers because it will be available internationally, and it will encompass virtually all wireless and wireline communications networks. The ETS will support authorized preferential treatment of many types of communications including voice, video, database access, text messaging, e-mail, FTP, and web-based services.

The ETS Standards Development project conducts laboratory studies, develops requirements and specifications, and performs security analyses to further the approval of standards supporting National Security/Emergency Preparedness (NS/EP) and Critical Infrastructure Protection (CIP) initiatives. This project is funded by the National Communications System (NCS), a part of the Department of Homeland Security (DHS). The project's work supports NCS in its mission to protect the national telecommunications infrastructure and to ensure the responsiveness and availability of essential telecommunications during a crisis.

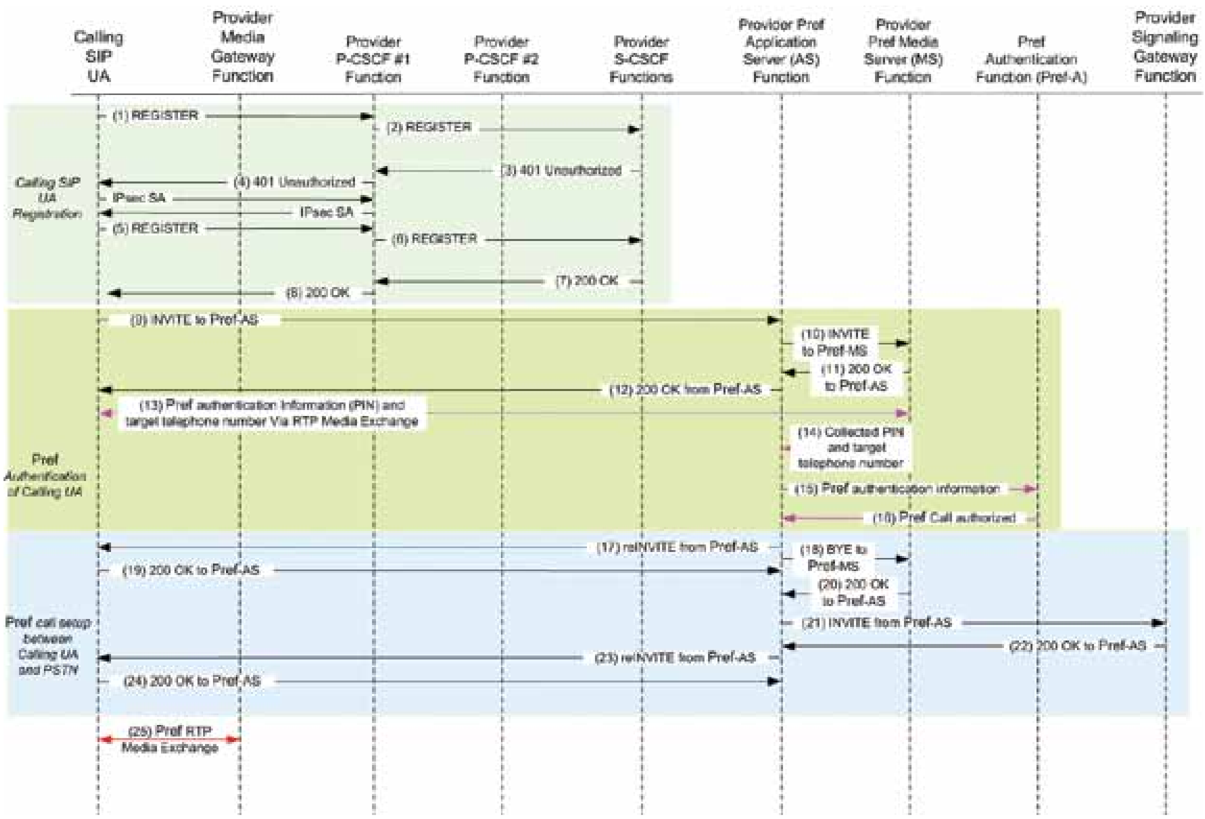
The ETS Standards Development project provides contributions to three standards development organizations. The first is the International Telecommunication Union's Telecommunication Standardization Sector (ITU-T) Study Group (SG) 9. The other two standards development organizations are two American National Standards Institute (ANSI)-accredited groups: the Alliance for Telecommunications Industry Solutions' (ATIS) Performance, Reliability, and Quality of Service Committee (PRQC), and the Society of Cable Telecommunications Engineers (SCTE). ITU-T SG 9 is the Lead Study Group, internationally, on integrated broadband cable and television networks, and the SCTE produces North American Standards for the cable industry. PRQC works in the areas of quality of service (QoS), reliability, and user-plane security and produces North American Standards. In SG 9, ITS develops Recommendations to support preferential telecommunications services and user authentication. One 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 their delivery of voice, data, and multimedia communications.

ITS' Participation

In PRQC, ITS provides ETS expertise relating to priority support and network security. During FY 2009, an ITS engineer served as coeditor of several ANSI and ATIS standards and technical reports. These reports provide guidelines, specifications, and requirements for aspects of ETS communications and network and computer security. Also, an ITS engineer served as the Vice-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 and IPCablecom2 families 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 deployed worldwide. IPCablecom2 has recently been approved, and equipment is in production and will be deployed in the coming years.

One goal of this project is to identify additions or changes needed to support GETS-like capabilities. This effort also involves work with the Internet Engineering Task Force (IETF), since many of the underlying protocols used in IPCablecom2 (as well as some of the ETS mechanisms) are under development in the IETF. An ITS engineer served as editor



VoIP Preferential Treatment using PIN Authentication Message Flow.

and principal author of ITU-T Recommendation J.260, "Requirements for preferential telecommunications over IPCablecom networks," in SG 9. An ITS engineer also serves as the editor of three Draft new ITU-T Recommendations:

- J.261, "Framework for implementing preferential telecommunications in IPCablecom networks."
- J.262, "Specifications for authentication in preferential telecommunications over IPCablecom2 networks."
- J.263, "Specifications for priority in preferential telecommunications over IPCablecom2 networks."

J.261 provides a framework for standardizing preferential services and priority user-authentication in cable networks. J.262 and J.263 provide specifications for IPCablecom2 networks that satisfy requirements set forth in J.260. These three Recommendations were submitted for approval under the ITU-T's Traditional Approval Process (TAP). They will reach final approval in early FY 2010.

The figure, from J.262, shows a call flow diagram indicating how a VoIP Preferential Call (e.g., an ETS call) would be established on an IPCablecom2 network connecting to a PSTN gateway using a PIN for authentication.

In FY 2010, ITS will continue to work on the development and standardization of ETS in ATIS PRQC, SCTE, and ITU-T SG 9. The project will address technologies in the NGN and interactions with the IPCablecom and IPCablecom2 networks. This work on ETS must be conducted with help from representatives of network providers and cable television equipment manufacturers, as well as NCS.

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Multimedia Quality Research

Outputs

- Technical contributions to VQEG.
- Technical contributions to ITU-T Study Group 9.

Overview

The distribution of audiovisual (multimedia) signals over wireless and wireline channels has increased exponentially in the last several years. Laptops, personal digital assistants (PDAs), and cell phones increasingly convey data using multimedia presentations. The digital technologies that transmit these audio and video signals occupy limited bandwidths, so the audiovisual compression often pushes the lower bounds of acceptable quality. To maintain their competitive edge, businesses in this competitive new market want objective quality measurements that are based on human perception.

ITS has a long history of successful research in the areas of speech quality and video quality assessment. The ITS Multimedia Quality Research project combines these separate lines of research to characterize and analyze the fundamental aspects of multimedia quality assessment. This involves two simultaneous efforts: First, to develop robust subjective methodology to measure audiovisual quality. This critical research need addresses the preliminary nature of existing ITU standards for measuring audiovisual quality. The second effort combines previously unrelated results of audio and video research into a single, cohesive audiovisual model. The vision is to develop a dependable algorithm that objectively predicts multimedia quality through a combination of audio quality, video quality, and audiovisual synchronization information.

Research Experiments

In FY 2009, to advance these goals ITS completed two subjective experiments and began a third. The first experiment, begun in FY 2008, explored the impact of audiovisual desynchronization on multimedia quality. This experiment used high-quality audio and video at CIF resolution that were systematically desynchronized, displayed on a computer monitor, and played over computer speakers in a sound isolation booth. Results show that viewers are more tolerant of desynchronization when audio lags behind video than when audio leads the video. This is likely due to the physics involved; since sound travels slower than light, we are used to seeing distant events before we hear them. An NTIA Technical Memorandum documenting the desynchronization experiment will be published early in FY 2010.

Figure 1. Example video content of source sequences.

The second experiment built upon work conducted in FY 2008 that used CIF resolution audiovisual sequences (see Figure 1 for sample video frames) to create both a range of audio impairments and a range of video impairments. In this 2008 test, subjects observed multimedia samples containing all combinations of these separate impairments. The full matrix design of this test allowed analysis into the relative importance of audio quality and video quality on audiovisual quality. This year's second phase displayed the audio and video samples to subjects separately. This yields three sets of Mean Opinion Scores (MOS) in total: the original audiovisual MOS, video MOS, and audio MOS. The independent measures of audio quality and video quality can be combined in a linear model to predict multimedia quality yield. This model and its error are plotted in Figure 2. An NTIA Technical Memorandum documenting these two related experiments and results from related studies by other laboratories will be published in early FY 2010.

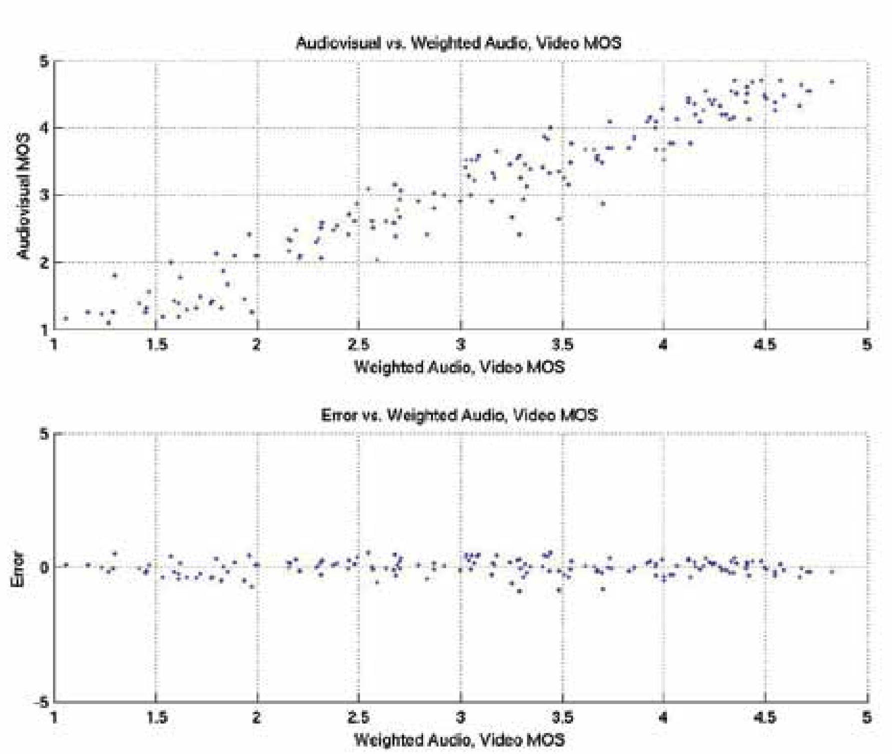

Figure 2. Audiovisual MOS predicted using a weighted combination of audio and video, MOS (top), and model errors (bottom).

The third experiment, begun but not yet not complete, further investigates the integration function that estimates overall audiovisual quality from measurements of audio quality, video quality, and audiovisual synchronization. This experiment builds upon the results of the second experiment (above) and improves on that experiment's design. Additionally, this experiment extends our understanding by presenting HDTV in a faux home theater. This experiment explores the implications of IPTV and video streaming over the Internet on audiovisual quality, while simultaneously investigating techniques for multimedia subjective testing methodology.

This work is conducted in conjunction with projects underway in the Video Quality Experts Group (VQEG) and the ITU-T Joint Rapporteur Group on Multimedia Quality Assessment (JRG-MMQA). The JRG-MMQA is an official body of the ITU and is formed from members of ITU-T Study Groups 9 and 12. The Multimedia Quality Research Project presented experimental results to VQEG, and compared audiovisual experimentation techniques with other researchers to better advance state-of-the-art techniques in subjective testing.

In FY 2010, the Multimedia Quality Research project will continue conducting subjective experiments to advance audiovisual subjective test methodology and develop multimedia quality assessment models.

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Wireless Network Measurement Methods

OUTPUTS

- Software-defined radio test instrument technologies.
- Wireless channel measurement techniques for high-speed data networks.

OVERVIEW

Broadband wireless data systems incorporate significantly greater operational mode complexity than legacy voice systems. In analog voice radio systems, a continuous signal is transmitted, and reception often depends primarily upon the amount of signal power available to the receiving device and the noise power that the system has to overcome at the receiving site. In these systems, relatively simple power-versus-frequency measurement methods are sufficient to determine the availability and quality of received signals.

By contrast, digitally-modulated, wireless data systems utilize higher system complexity to achieve higher capacity in the radio channel. The digital modulation itself is an example of this higher complexity. Sampled, digital, RF-modulation techniques quantize the signal in time as well as in some other parameter like frequency-shift, phase, amplitude, etc. The time quantization leads to synchronicity issues. A receiver must assure that it is synchronized at the RF level, often in both frequency and phase, as well as at the symbol level, i.e., the receiver carries precise information about the start and end time of a symbol. Loss of synchronicity at either level results in signal errors whose cause may be difficult to characterize.

Modern technologies like Wi-Fi, WiMAX, and LTE (Long Term Evolution) also embody a notion of rate-adaptive error correction and modulation. These devices change their error-correction strength and modulation methods on the fly based on sensed information about the current conditions of the radio channel. In general, this includes the concept of closed loop control, messages passing between mobile nodes and the base station that provide information about the local radio environment.

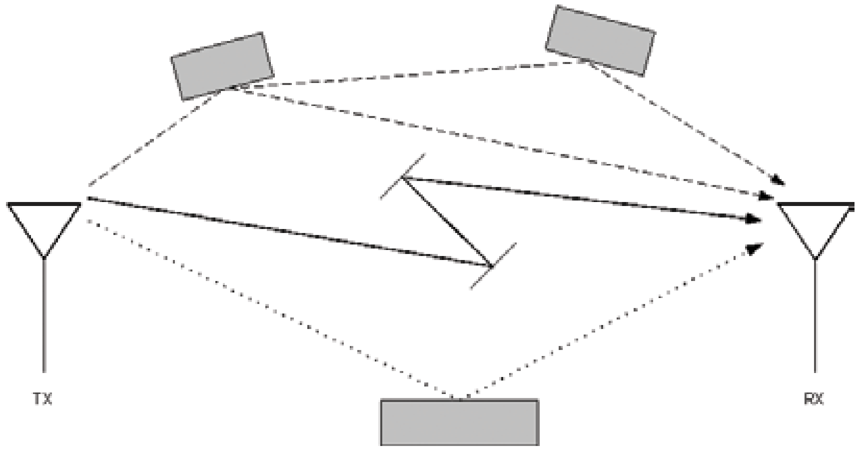
In turn, control messages imply control protocols. Systems of this type rely on proper adherence to well-specified protocols for control and messaging. These systems are often said to be "stateful," because they have precisely defined states that respond only to certain messages. Network failures can be caused by messages that are incorrect or incorrectly formatted or by messages that are correct in content but incorrectly sequenced.

As a result of increased complexity in protocols and control messaging, greater spectral efficiency is required. Spectrum is a scarce resource that is constrained by regulatory restrictions for any given wireless data service. Throughput rates are increased by measures like precoding, which reduce information redundancy, and sophisticated modulation schemes, which increase the number of bits transmitted by each wireless symbol. Also, measures like orthogonal frequency division multiplexing (OFDM) are employed to use the existing spectrum more efficiently.

WIRELESS CHANNEL MEASUREMENT TECHNIQUE DEVELOPMENT

Another technique that shows great promise is spatial multiplexing, often known as multiple input, multiple output (MIMO). Here, the gain and phase differences between radio channels that are spatially separated by as little as one-half wavelength at the frequency of interest are exploited. Separate information streams are converted into space-time codes and sent by spatially-separated transmitting antennas, using the same spectral band. Each receiving antenna receives a weighted-vector sum comprising all of the encoded streams, and is able to resolve a single stream through knowledge of the properties of the radio channel that carried it. In the perfect case of uncorrelated radio channels, significant gains in the information carrying capacity of the wireless system can be achieved.

In order to reach the potential spectral efficiency gains of MIMO, the presence of multiple uncorrelated radio channels is required. Paradoxically, this means that MIMO operates most efficiently in environments that exhibit a high degree of multipath behavior, which is exactly the type of environment that ordinary, single input, single output (SISO) wireless systems have the most trouble in resolving. This situation occurs because high multipath conditions give rise to closely-spaced radio channels that are different enough to be easily decorrelated at the receiver. As shown in the figure, this condition generally means that signals traversing different radio channels are received at different angles of arrival (AOA). In fact, in the direct line-of-sight (LOS) conditions that are most favorable to normal SISO wireless systems, spatial multiplexing collapses and MIMO systems exhibit no better throughput characteristics than other radio technologies.



Multipath environments give rise to different angles of arrival.

The critical dependence of spatial multiplexing upon a high-scattering environment means that MIMO is extremely sensitive to the size and configuration of scattering elements in the radio channel as well as the wavelength of the radio signal being transmitted. Essentially, objects considerably smaller than one wavelength may not affect the radio path enough to produce multiple uncorrelated radio channels. This is of particular interest since radio spectrum in the 700 MHz region has recently been made available for telecommunication services. Signals at this frequency have larger wavelengths than those in many other commercially available communication bands. This leads to better propagation characteristics in line of sight conditions, but makes prediction of the utility of MIMO in any given environment somewhat more complicated.

Measurement of MIMO involves knowledge of the radio channel transfer matrix. This matrix expresses the instantaneous transfer function between pairs of transmit and receive antennas as a matrix of complex numbers, where the magnitude represents the gain of the radio channel between two antennas, and the angle represents the phase, or time delay of the channel. Analysis of this matrix provides measures of the ability of the channel to carry MIMO signals.

SDR Test Instrument Technologies

Through paper studies and simulations, as well as the creation of a software defined radio (SDR) channel sounder, the Wireless Network Measurement Methods Project is investigating the properties of MIMO in multiple propagation environments. The primary metric of interest is radio channel correlation, and it is difficult to measure this parameter. Using relatively inexpensive SDR-based tools, a radio-channel sounder with a bandwidth of 25 MHz has been created to determine the characteristics of radio channels in multiple propagation environments. The current design operates in the 2.4 GHz spectral region, and produces a pseudorandom number (PN) sequence encoded binary phase shift keyed (BPSK) signal that can be used to probe the radio channel. The special correlation properties of the PN sequence allow this signal to represent a synthetic impulse, yielding information about the transfer function, or impulse response of the radio channel.

Currently, ITS is testing this SDR system in outdoor environments to determine its ability to resolve various types of scattering mechanisms. It will later be transitioned to a 700 MHz channel sounder as experimental spectrum becomes available. This device and another measurement system, based on the properties of real time spectrum analyzers (RTSA), will be used to investigate the channel correlation characteristics of various propagation environments, including radio channels that are decorrelated through cross polarization. In this way, the strengths and weaknesses of MIMO processing can be evaluated to allow informed decisions about its use in Federal high speed wireless data systems.

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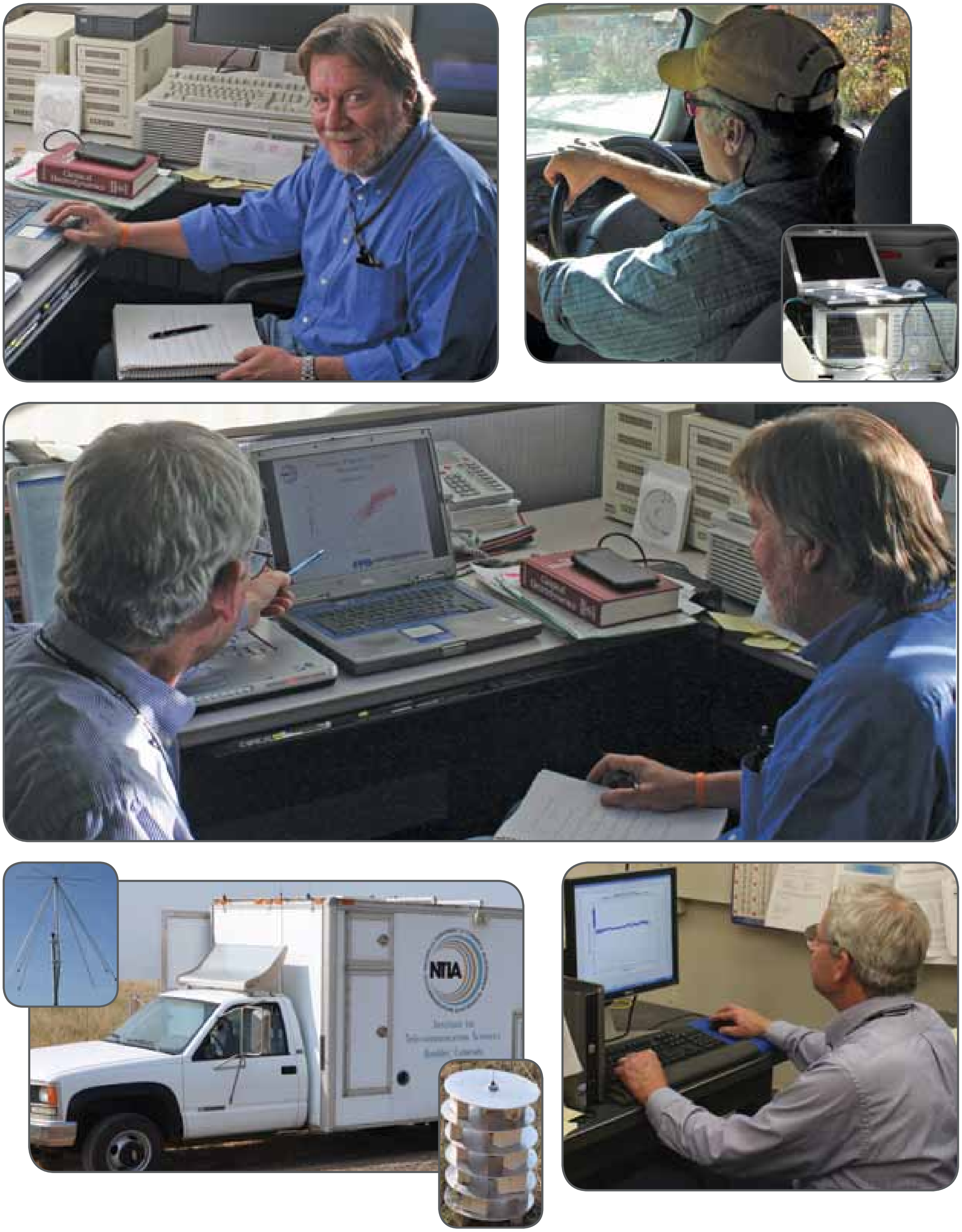

In FY 2009, Telecommunications Engineering, Analysis, and Modeling Division engineers conducted a series of field measurements in order to develop new propagation models with specific applications like very low antenna heights and short distances. The field measurement campaign was extensive, including several types of environments and unique path characteristics (photographs by S. Carroll).

Telecommunications Engineering, Analysis, and Modeling

The Telecommunications Engineering, Analysis, and Modeling Division conducts studies in these 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, jamming, 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 TA Services project, which offers custom analytical tools via an on-line cooperative research and development agreement. Propagation prediction models are being incorporated into GIS formats and web-based access. Modeling is one of ITS's core strengths enabling contributions to international and national standards bodies. Propagation models are incorporated with terrain databases and other data. Adaptations of historic models, and those for specialized situations have been developed, enhanced, and compared.

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Areas of Emphasis

Engineering

Interference Issues Affecting Land-Mobile Systems ITS participates in ATIS subcommittee WTSC-RAN (Wireless Technologies and Systems Committee—Radio Access Networks) and in ITU-R WP 5D. ITS developed PCS interference models for CDMA and W-CDMA. The project is funded by NTIA.

Public Safety Video Quality (PSVQ) The PSVQ project conducts subjective tests on video compression and artifacts that are shown to expert viewers. From these data, NTIA/ITS has made recommendations for video standard Rec. ITU-T P.912. Also, ITS leads yearly VQiPS workshops. This project is funded by NIST/OLES.

Fading Characteristics Verification ITS participates in many aspects of public safety communications. This project is investigating whether the fading experienced with public safety communications can be modeled using Rayleigh fading. This project is funded by NIST/OLES.

Analysis

Telecommunications Analysis Services ITS provides network-based access to research results, models, and databases supporting wireless system design and evaluation. These services are available to government and non-government customers and are funded through an on-line CRADA.

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

Communications Alternatives Study The Institute has developed a unique software tool to analyze antenna coverage from multiple locations. This work was done for Acadia National Park, Department of the Interior.

Modeling

Broadband Wireless Standards ITS develops radio propagation algorithms and methods to improve wireless system spectrum usage. ITS prepares technical standards supporting U.S. interests in 3G broadband wireless systems for ITU-R Standards Group 3, WPs 3J, 3K, 3L, 3M. ITS is active in path-specific model development for WP 3K and its development of ITU-R Recommendation P.1812. Work is funded by NTIA.

Short-Range Mobile-to-Mobile Propagation Model Development and Measurements ITS is developing a model for short-range (1 m to 2 km) propagation between mobile radios. The propagation work consists of modeling and field measurements. This project is funded by NTIA/OSM.

Ultra-low Antenna Height Modeling and Measurements ITS is developing a model for ultra-low antenna heights. This work consists of extensive field measurements in a project funded by the U.S. Naval Research Lab.

Interference Issues Affecting Land-Mobile Systems

Outputs

- Self-interference models for evaluating CMRS technologies and deployment of adjacent-channel systems.
- Technical contributions to industry-supported efforts for predicting, identifying, and mitigating interference-related problems.
- Technical support for international and national standards development organizations.

Overview

The deployment and development of next-generation commercial communication systems creates more demand on the radio spectrum, which worsens the problem of limited available spectrum. Spectrum sharing is necessary to allow for each user's requirements of the available spectrum. The need to implement true universal coverage (worldwide roaming) places different demands on spectrum allocations depending on the location of the user and provider. In addition, the increasing telecommunication needs of civil and Federal users (such as emergency responders) have their own spectrum requirements.

Interference Issues

Until dedicated communication systems for emergency services are deployed, Commercial Mobile Radio Services (CMRS) will remain vital for emergency communications. As a result, wired and wireless communication services will experience elevated usage rates during emergency situations. This sudden influx of traffic by private, commercial, civil, and Federal users will result in system overloads, a decrease in signal quality, and further disruption of service in affected areas. Beyond the physical damage caused by destructive events, additional factors such as co-channel and adjacent-channel interference and the operation of multiple, independent, non-interoperable systems servicing the same geographical area, will further reduce wireless network channel capacity. One way of coping with degraded infrastructure is to deploy temporary equipment to supplement the surviving system. National security/emergency preparedness (NS/EP) planners and network operators require knowledge of interference issues, system dynamics, and load patterns to efficiently and effectively deploy supplemental equipment in an overloaded environment.

Spread-spectrum technologies, which make efficient use of allocated spectrum and are relatively unaffected by noise, are used in current cellular systems and will become even more prevalent in next-generation systems but suffer from limitations due to issues such as co-channel interference. Work in detecting, identifying, and mitigating co-channel interference in congested environments requires tools that can characterize the interference experienced by air-interface signals, predict levels of interference, and identify sources of interference.

To support this work, ITS developed an interference model for two CDMA-based systems: the TIA/EIA-95B standard (Figure 1) and W-CDMA (Wideband CDMA). The model produces a representation of an instantaneous air-interface signal containing outputs of multiple base stations with variable numbers of mobile users for each base station and can assign relative power levels for each individual mobile user; it includes both forward- and reverse-link processes. The model calculates each channel's sampled QPSK or OQPSK signal contribution separately, then sums all signals identified in a specified scenario together to form a composite output signal. The power level for a single channel is a gain factor of the baseband filter and is set separately for each channel. There is no error correction added to the input sequence, only spreading codes and modulation processes are used. 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. Using these simulations, existing congestion problems can be solved and potential problems can be anticipated and avoided.

In complex, congested urban environments manufacturers need a better understanding of air-interface propagation characteristics. In environments with many obstructions, such as buildings or terrain, wireless systems often encounter diffraction effects, where wireless signals can still have signal loss even when the signal is not completely blocked. Several diffraction models exist that calculate the power loss in such situations, each with strengths and weaknesses. To help improve the accuracy of propagation calculations, ITS has made a comparative analysis of individual diffraction models to determine the best model for a given situation (see Figure 2).

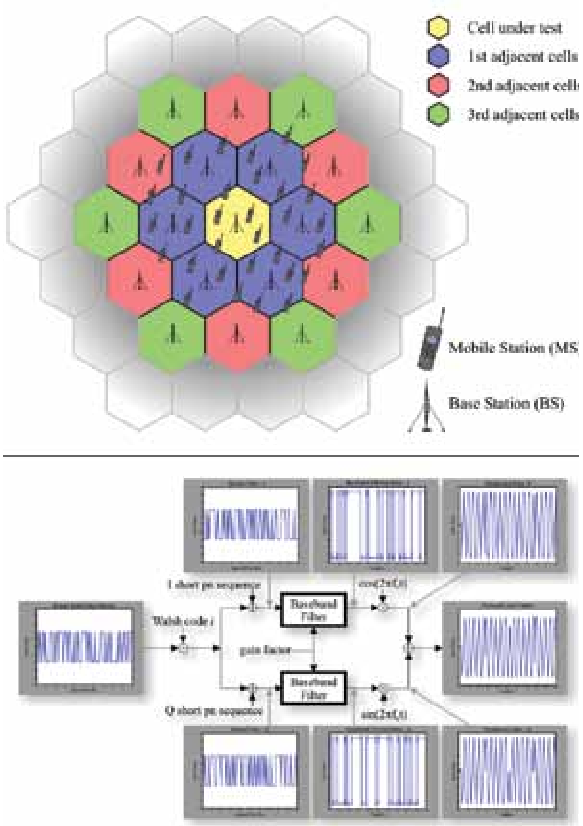

Figure 1. A typical cellular deployment scenario (top) and the signal generation block diagram of a typical base station (bottom).

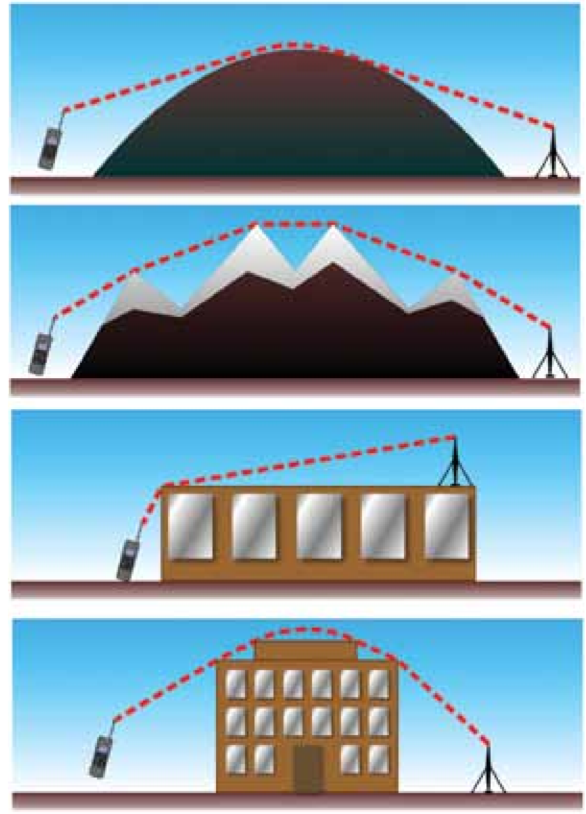

Figure 2. Based on the obstruction's geometric properties and the frequencies in use, different knife-edge diffraction models should be used.

Standards Development

ITS provides propagation and interference expertise through participation in national and international standards development organizations. ITS contributed to the understanding of inter-PCS interference by participating in the development of the Telecommunication Industry Association's (TIA) Technical Service Bulletin "Licensed Band PCS Interference" (TSB-84A). This handbook was a first step in characterizing the interfering environment caused by large numbers of active users and competing technologies. Since the completion of this work, coverage of interference issues concerning all mobile communication systems has been adopted by the Alliance for Telecommunications Industry Solutions (ATIS) sub-committee WTSC-RAN (Wireless/Mobile Standards – Radio Access Networks). Work on the successor to TSB-84A is currently underway as Issue P0017, "Proposed Joint ATIS/TIA Standard on Coexistence and Interference Issues in Land Mobile Systems." ITS continues its involvement in these activities as issue champion and editor.

The International Telecommunication Union—Radiocommunication Sector (ITU-R) is the lead organization in the effort to coordinate worldwide development of future telecommunication systems and spectrum allocations. ITU-R Working Party 5D (WP5D) is developing standards for the group of future technologies referred to as IMT-2000 and IMT-Advanced. Coordinating world-wide frequency allocations is a near-impossible task, given the disparity in the historical evolution of frequency use and requirements in each country. Interference and coexistence issues are a primary concern as more systems try to use the same limited quantity of spectrum on a worldwide basis. In support of this work, ITS supplies technical support to the U.S. delegation to WP5D.

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Public Safety Video Quality

OUTPUTS

- A User Guide to help public safety agencies specify video equipment.
- Technical contributions to standard bodies to establish video quality measurements and standards for the public safety community.
- Technical contributions on video quality standards to the sponsor.

OVERVIEW

Public safety agencies often purchase video cameras and other video equipment without adequate guidance. Unfortunately, this equipment may not always be of high enough quality for use in meeting their goals. This is because, until recently, there were no technical standards for video equipment used for public safety applications. To assist agencies in selecting appropriate video equipment, ITS is conducting video-quality research to determine standard parameters for levels of quality of video systems based on the specific needs of public safety practitioners and their applications. ITS is working on behalf of the Department of Homeland Security (DHS) and the National Institute of Standards and Technology Office of Law Enforcement Standards (NIST/OLES) to ensure that first-responder video systems communicate clearly and accurately.

VQiPS CONFERENCES AND WORKING GROUP

In February and September of 2009, ITS hosted two conferences on Video Quality in Public Safety (VQiPS)(see figure). VQiPS' goal is to bring all users of video in the public safety community together to discuss public safety video needs. The conferences brought together a wide range of participants including local, state, and Federal representatives from a variety of disciplines including law enforcement, fire services, and Emergency Medical Services (EMS) as well as representatives from nonprofit research organizations, academic institutions, and industry leaders. Ultimately, the VQiPS conference will help to coordinate efforts in establishing quality requirements for video used in public safety applications.

Participants gathered to discuss the major video quality challenges that are affecting their agencies and begin working on appropriate, application independent solutions, by focusing on the common elements across the disciplines. Through these conversations, the need for a Working Group (WG), which would build on the tasks begun at the conference, became apparent. The VQiPS WG was formed to serve as a collaborative agent within the public safety community aiming to effect change across the range of public safety video communications, making an immediate impact on the video user community by arming consumers with the tools needed to purchase and employ the right video systems for their needs.

VQiPS INITIATIVES

The WG divided into four subgroups to focus on the project's four main initiatives:

- Develop a User Guide—to assist with communication between public safety agencies and equipment manufacturers.
- Create a glossary of video terms—to establish a common language to facilitate communication among different organizations.
- Compile generalized use classes—to educate consumers about their video applications and how they affect quality requirements.
- Research existing video quality standards—to have a basis to build upon as needed.

The User Guide is the central framework for containing and disseminating the work of the other three initiatives, and for the publication of any performance specifications developed by ITS in the future. Its mission is to develop technical guidelines for use in video system design and specifications that achieve the desired system usage across multiple disciplines. The User Guide will inform policy makers and procurement officials who are engaged in the selection of video systems. The desired usage across disciplines will drive applicable technical requirements. These requirements will facilitate the preparation of video system specifications for the end user.

Since this document is intended for use by agencies of all sizes, the majority of the document is dedicated to defining the core components that apply to any video system independent of the scale. The purpose is to provide an organized, educational summary of the fundamental components of a video system to personnel within any public safety agency.

Multiple agencies, research organizations and industries discuss their video needs at VQiPS (photograph courtesy of Touchstone Consulting Group).

The scope is limited to identifying, organizing, and defining the fundamental components of a video system, and providing references to performance specifications, where they exist. These components are necessary for any basic video system, and each component has a direct effect on the quality of the video signal that is eventually viewed by the end user (i.e., each has the potential to alter the signal in a way that affects its ability to be used).

Generalized Use Classes

The specifications that apply to any video system depend on how it will be used. The intended audience for the User Guide includes many agencies which combine a broad range of video knowledge and ways in which they apply video in their public safety roles. Even though various applications may seem very different, they may actually have the same minimum requirements to perform the desired recognition task. Therefore, it was determined that usage scenarios should be developed that are based on the aspects of the video system that most affect the ability to perform recognition tasks, and which are not specific to one particular agency's application. These aspects must be generic enough to apply to any target recognition application. Each unique combination of these aspects forms a Generalized Use Class (GUC).

The WG identified five parameters or aspects of the scene content and use characteristics they believed to have the greatest potential impact on the quality of the video content as seen and used by the end user. These include: usage timeframe, discrimination level, target size, scene complexity, and lighting level. The combinations of the end user's specific needs in these five areas would comprise their GUC. Once an agency has determined its GUC, subsequent sections of the User Guide will aid the user in determining which standards and specifications apply to the components of the core video system for its specific GUC.

Future Work

In June 2010, VQiPS will release version 1.0 of the User Guide. Version 1.0 is qualitative – it will describe the framework and the concept of a GUC, and will provide some general qualitative guidance. Future versions will contain links and references to quantitative specifications and standards. VQiPS will continue as a twice-yearly workshop to continue to address the WG initiatives.

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Fading Characteristics Verification

Outputs

- Fading characteristics of the land mobile radio channel at 162 and 793 MHz.
- Technical contributions to public safety standards bodies.

Overview

Land mobile radio (LMR) systems are used primarily by public safety organizations in mobile environments where dynamic path loss, multipath fading, noise, and interference can greatly affect communications. As public safety communications systems obtain higher spectral efficiency and more high-speed data applications, the properties of the communications medium become more significant, requiring a better understanding of the channel fading characteristics. The fading characteristics verification project will help ensure that services, such as public safety video, will maintain operational continuity in mobile environments.

Project Challenges

At any given instant in time, the radio channel can be characterized by a complex number, consisting of a magnitude and a phase. The magnitude indicates the instantaneous radio-channel attenuation or gain, and the phase indicates the instantaneous channel-transfer-function phase. Generally, the magnitude value, or the fading loss, has been of primary interest due to the decrease in the signal-to-noise ratio (SNR) at the radio receiver. Since this is typically represented as a slow-varying function (over time regimes of tens or hundreds of milliseconds for land mobile radio), relatively simple measures like automatic gain control (AGC) can be used to mitigate such impairments. The probability distribution of signal attenuation, or fast fading, is typically modeled as a Rayleigh or Rician distribution dependent on the presence of a direct ray. The Rayleigh fading model has been the most widely used model for testing Project 25 radios. The Rayleigh model is considered to represent the worst-case condition because it does not contain a line-of-sight component.

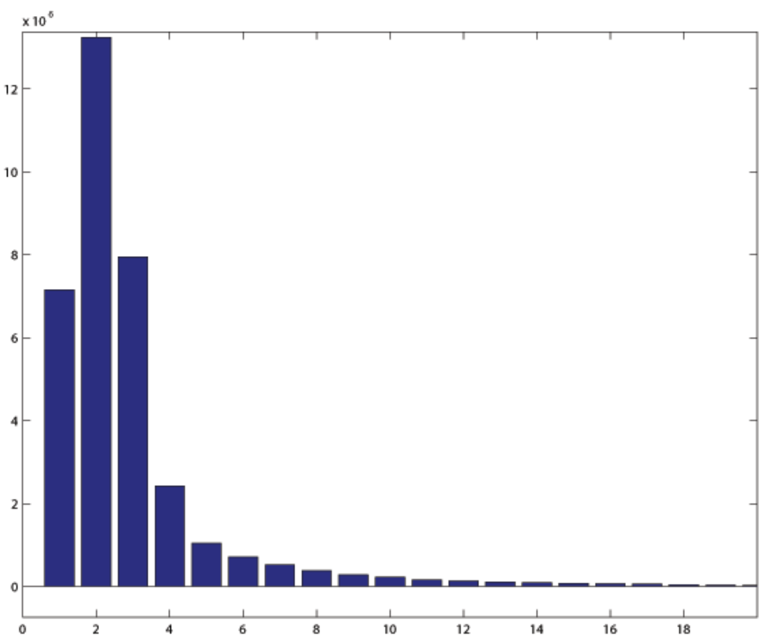

Figure 1. Probability distribution of measured data signal attenuation.

With the advent of higher speed systems with short symbol times relative to the carrier, the channel phase is becoming more important. The phase variation of the channel is not well-studied, since empirical data about channel phase is not widely available. Analytical results about channel phase correlation based on Rayleigh's assumptions are available, but these results need to be compared to real environments. The significance of the radio channel's phase distribution is an important area of research made more significant by the widespread use of high-speed digital modulations. If the radio channel is imparting rapid-phase variations, in time regimes similar to a symbol period, these will manifest as bit errors in the decoded signal.

Ongoing Measurements

This project's measurement effort will be conducted in several different environments that are relevant to public safety. In FY 2009, ITS initiated the project and conducted multiple field measurements in rural and urban low-rise environments. The measurement system has undergone several iterations for improvements. The test system consists of a transmitter that

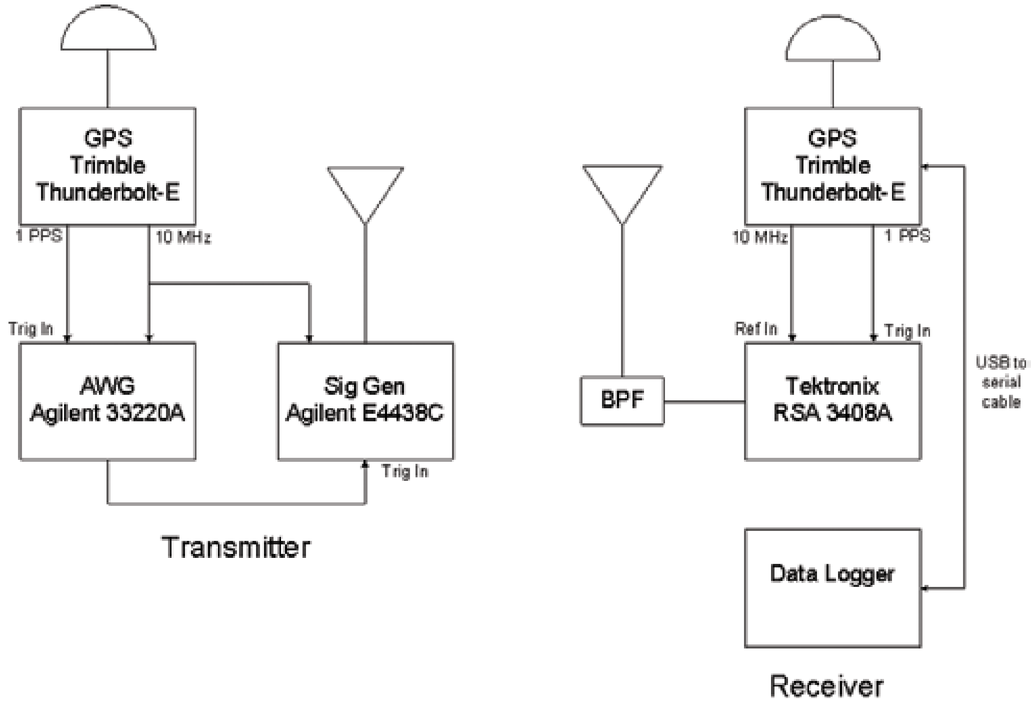

Figure 2. Fading Characteristics Verification project measurement system.

will be placed at a static location and a mobile receiver, which will simulate a LMR base station and mobile subscriber scenario. Several different locations and paths will be used, including rural (Table Mountain), urban low-rise (downtown Boulder), and urban high-rise (downtown Denver), to provide a wide range of propagation environments with differing multipath characteristics. Frequencies of 183, 430, and 700 MHz will be used as representative public safety channels. Measurements will be performed at speeds between 8 and 100 km/h (i.e., walking and vehicular speeds). Actual radio channel measurements will be conducted numerous times to ensure statistically significant results. The resultant data will be analyzed to determine how closely the measurements align with multiple fading distribution models. The results of this effort will be presented to the Project 25 standards bodies as well as other appropriate venues.

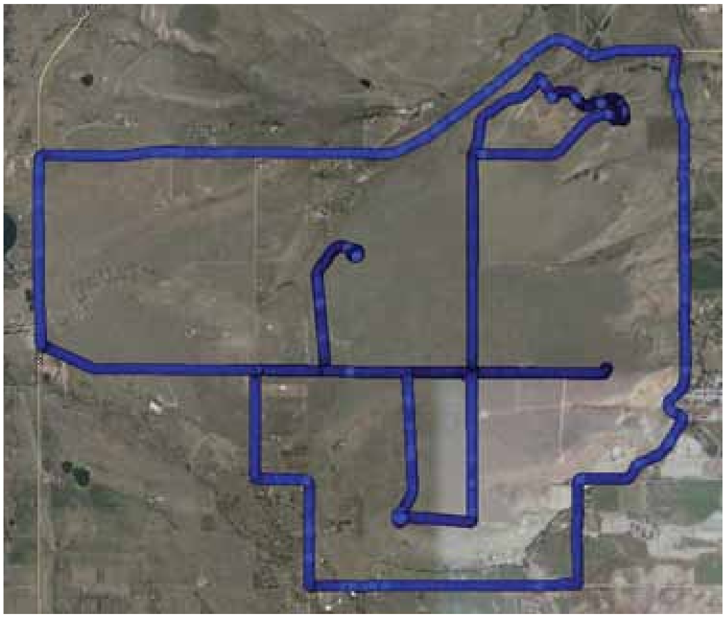

Figure 3. Measurement path at the Table Mountain Field Site.

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Telecommunications Analysis Services

Outputs

- Internet access on a cost-reimbursable basis linking U.S. industry and Government agencies to the latest ITS engineering models and databases.
- Contributions to the design and evaluation of broadcast, mobile, and 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.
- Online CRADAs that allow users to task ITS to develop special models or perform special analysis tasks.

Overview

The Telecommunications Analysis Services (TA Services) program provides industry and Government agencies with access to the latest ITS research and engineering outputs on a cost-reimbursable basis. It uses a series of computer programs designed for non-technical users with minimal computer expertise or 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.

TA Services also allows users to work closely with ITS engineering staff to develop small-scale research and development models and programs via the online Cooperative Research and Development Agreement (CRADA) options. Users can create task items for a cost of up to $25,000 per CRADA. Through the TA Services Website, new CRADAs can be quickly created as needed.

Available Models and Databases

Currently, TA Services provides access to many databases and services including partial world-wide terrain data with 1-arc-second (30m) resolution for CONUS and 3-arc-second (90m) and world-wide GLOBE (Global Land One-km Base Elevation) data, the U.S. Census data for 2000 and 1990, Federal Communications Commission (FCC) databases, and geographic information systems (GIS) databases (ArcInfo). For more information on available programs, see the TA Services entry in the Tools and Facilities section (page 80) or call one of the contacts 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 U.S. customers with active accounts on the system. Customers can activate models, enter information about their broadcast equipment, and produce generic transmitter coverage diagrams for a typical broadcast application,

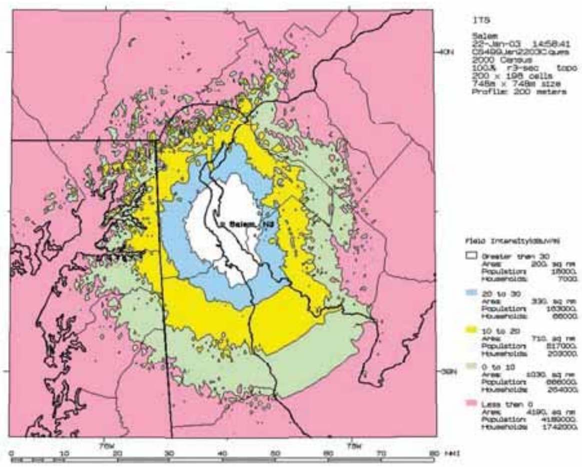

Figure 1. Sample output of the CSPM model of a broadcast transmitter in New Jersey.

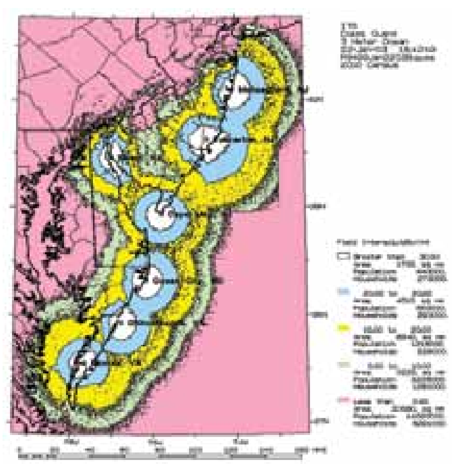

Figure 2. Composite coverage of several Coast Guard stations located along the East Coast.

similar to Figure 1, using the Communications System Performance Model (CSPM) program.

These coverage models follow FCC guidelines and requirements to show both the signal coverage and the population that resides within the various analysis contours. Users can also combine individual transmitter coverage data into a composite coverage simulation such as that shown in Figure 2. This allows the user to determine both single transmitter performance and integrated system performance.

Notable Projects

TA Services has assisted U.S. broadcast television providers with the transition to digital television (DTV) by providing an application-specific model for use in advanced television analysis (high-definition television, advanced television, and digital television). This model allows users to create scenarios of desired and undesired station mixes. The model also maintains a catalog of FCC recorded television stations and advanced television stations from which these analyses are made.

The results of these studies show those areas with new interference and the population and number of households within those areas so that designers can mitigate possible situations before they become a problem. The model can also determine how much a selected station's interference is affecting other stations. This allows engineers to make modifications and then determine the effect those modifications have on the interference emissions that affect other surrounding stations. In addition to creating graphical plots of signal levels, the program creates tabular output that shows the distance and bearing from the selected station to each potential interfering station as well as a breakdown of the amount of interference each station in the study contributes to the total interference.

TA Services has also assisted the U.S. Public Broadcasting System and the National Weather Service in determining 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. 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.

The National Public Radio Laboratories used the CRADA capabilities to develop an In-Band, On-Channel (IBOC) interference model and plans to do similar development for HDTV.

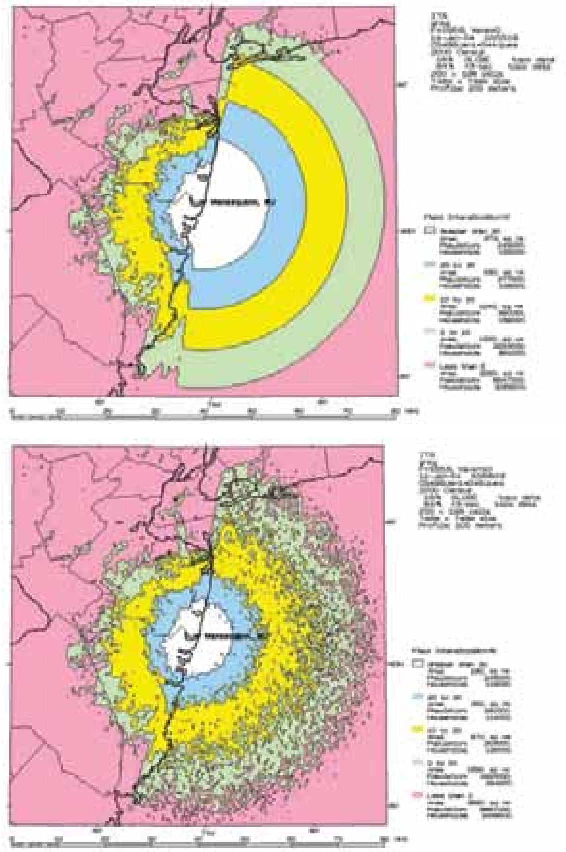

Figure 3. Coverage studies without (top) and with (bottom) an ocean clutter loss addition to CSPM.

An example of a simple model change that can be quickly accomplished through this CRADA capability is shown in Figure 3, which shows the effect of adding an ocean wave-clutter attenuation factor to CSPM.

In FY 2009 ITS began the effort to upgrade the TA Services System to a new Geographic Information System (GIS) Web-based interface that will place the power of advanced GIS functions and features in the hands of TA Services customers. This work will continue in FY 2010.

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Geographic Information System (GIS) Applications

Outputs

- A desktop Geographic Information System (GIS) software suite for running 2D and 3D ITS developed and 3rd party propagation coverage models for one or more transmitters (LFMF, HF, and VHF).
- GIS software for creating composite, interference, overlap, point-to-point, and coupled outdoor/indoor coverage models (VHF).
- GIS software for incorporating FCC database downloads into coverage models.
- Web-based GIS 2D propagation models for one or more transmitters (VHF).

Overview

Industry and Government organizations rely heavily on modern communication systems, which are becoming more complex and abundant as demand for this type of communication increases. In order to help these organizations to better understand the changing scene of wireless communication, ITS has developed an enhanced suite of propagation modeling applications based on Geographic Information Systems (GIS).

The databases available for GIS use, including terrain, satellite and aircraft imagery, ground transportation infrastructure, building data, and population distribution are becoming more available and affordable. These databases can be easily incorporated into GIS systems and can be shared among users in web-based or standalone GIS applications. ITS has developed generic, application-specific GIS programs that aid Government agencies, private cellular companies, public and private radio and television stations, transportation companies, and consultants in the performance of their missions to efficiently manage the telecommunications infrastructure of the United States.

Communication Systems Planning Tool

The primary ITS-developed, GIS-based tool is a desktop computing tool called the Communication Systems Planning Tool (CSPT). CSPT is a menu-driven propagation tool suite developed for frequencies from 150 kHz to 20 GHz that allows the user to select models and use a variety of image catalogs and terrain libraries that cover most of the world. Users can create specific analysis areas using this data and can perform propagation scenarios for their specific application. Applications can range from world-wide outdoor coverage studies to indoor propagation studies of one building in an urban environment. Figure 1 shows a sample transmitter coverage for a small portion of New York City in both 2D and 3D.

The CSPT tool also allows the user to create a simple rendition of a building, including windows, doors, and interior walls so that the tool can create coupled indoor/outdoor (shown in Figure 2) or outdoor/indoor coverages.

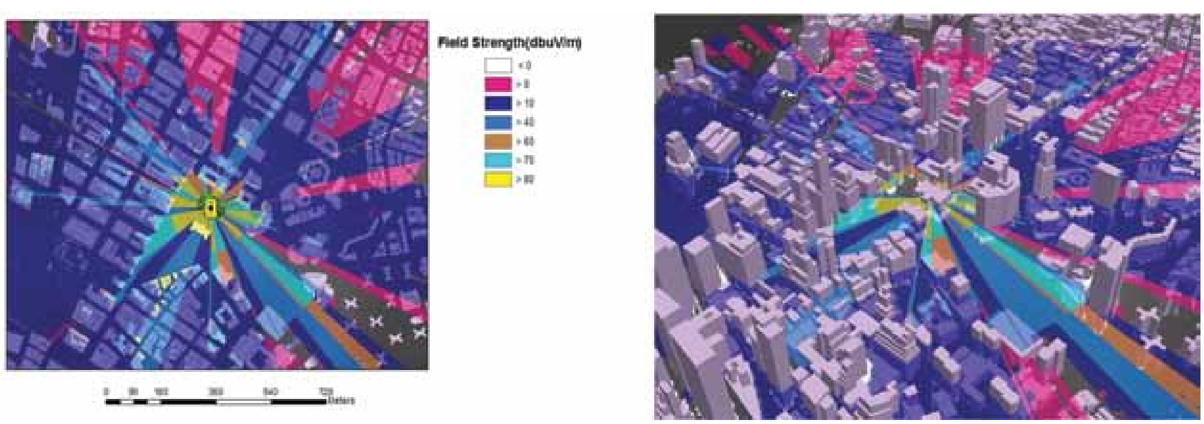

Figure 1. A CSPT-VHF study for New York showing both 2D and 3D results.

The CSPT also includes the ITS HF ICEPAC model and the ITS LFMF System 3 model which provides analysis capabilities from 150 kHz to 2 MHz for areas as large as the entire world. The CSPT tools can download FCC FM and TV databases, perform overlap, composite, and interference studies and can report demographic information from the 1990, 2000 and 2007 (estimated) Census Population databases.

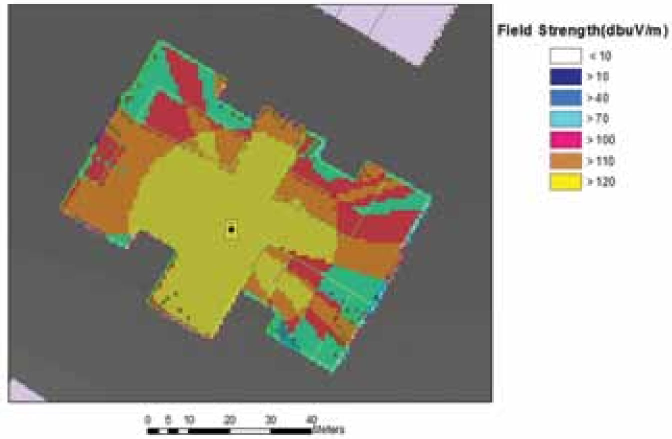

Figure 2. A CSPT-VHF indoor/outdoor study in New York.

Propagation Modeling Website

Over the last three years, the Institute has been upgrading the CSPT to a cutting-edge web-based GIS solution called the PMW (Propagation Modeling Website), shown in Figure 3.

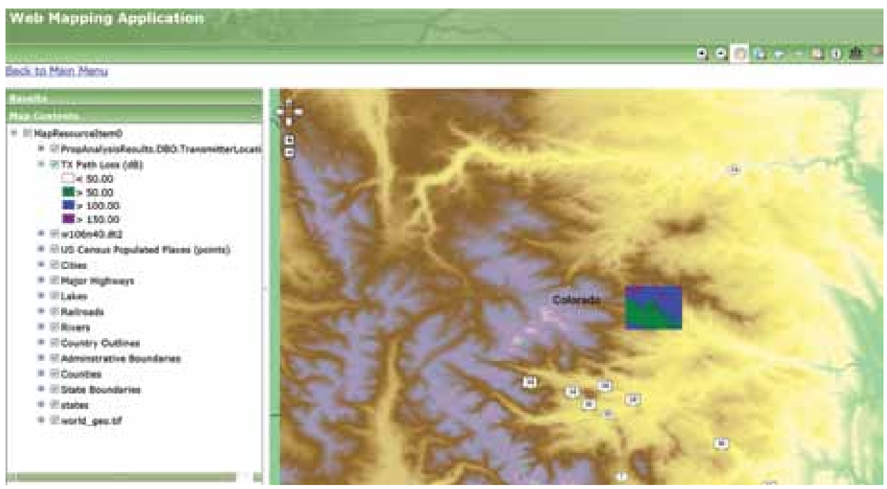

Figure 3. PMW analysis showing radio propagation path loss in Colorado.

The PMW allows users to log into a central server and use one database server to perform storage, retrieval and analysis. Analysis is currently performed in single-transmitter or batch-transmitter mode using the TIREM or ITS Longley-Rice model. The PMW is currently customized to fit the needs of our DOD sponsor and operate on their internal, secure network. Because the PMW contains publicly available propagation models, with some software modification it could be deployed to the ITS server for public use. The PMW solution integrates COTS (commercial, off-the-shelf) GIS, database, and web-development products in a fully-customizable software programming environment that can be tailored to meet individual customer needs. The PMW currently displays 2D propagation analyses; these displays will become 3D as customizable GIS web technology becomes available.

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Communications Alternatives Study

Outputs

- Coverage plots of the present communications capabilities at Acadia National Park.
- Single, double and triple alternative base station location evaluations.
- Analysis tools to assess the viability of each alternative.

Overview

Recently, ITS has been tasked by the National Parks Service (NPS) to evaluate the communications capabilities within Acadia National Park. Acadia National Park is located on the Maine coast and protects over 47,000 acres of land. Acadia National Park receives over 2 million visitors annually. The park communications consist of VHF, UHF, and Wi-Fi networks. These systems are predominantly used for public safety applications, but also serve education, research, and administrative functions.

The VHF system that services the park is the main focus of this ongoing analysis effort. ITS has an array of tools to conduct this analysis, such as the Communication System Performance Model (CSPM). The CSPM was used in this effort to verify the current communications environment in the park and access alternatives. Figures 1 and 2 show the composite coverage of an alternative communications solution from Cadillac Mountain, the highest point in the park, and Isle de Haut. In each figure, two base stations are modeled to examine how well communications are maintained relative to the present VHF communications coverage.

Alternative Communications Scenarios

As part of this effort, ITS is developing a series of analysis tools that will help automate the examination of alternative communications coverage within the park. Outputs from these new tools, used in conjunction with the propagation model output available from the CSPM, will be used to programmatically rank alternative communications scenarios. These new tools are designed to quickly identify the advantage of one, two, or three antenna alternatives, relative to present communications coverage. The most promising alternative solutions (among a possible multitude) can then be examined in detail leading to a smaller number of superior and practical solutions for this and other applications.

ITS is examining several quantitative metrics based on signal level statistics, coverage area, interest areas, and transportation path signal availability.

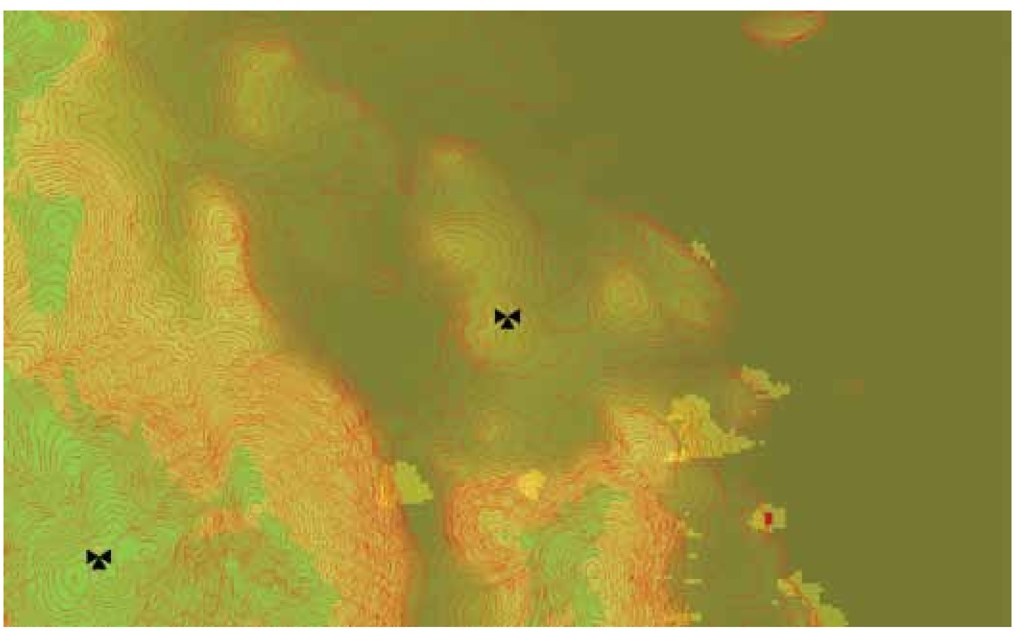

Figure 1. Acadia NP VHF communications alternative #1.

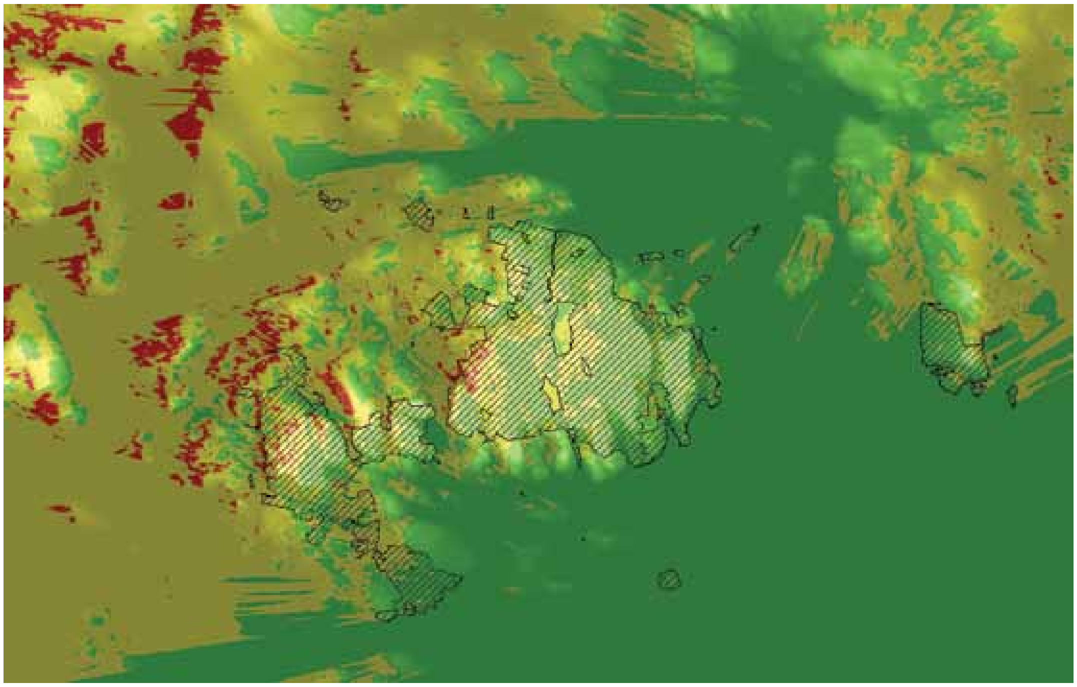

Figure 2. Acadia NP VHF communications alternative #2.

Mechanisms to use these new analysis metrics can help identify promising candidates among alternatives. Ideally, many of these techniques can be incorporated into future versions of CSPM.

The development of new software tools was required to supplement and expand the functionality of existing ITS analysis tools. Because of a rather large set of alternative communication solutions, an analytical method to distinguish the best sites from many thousands of possibilities of one, two, and three antenna combinations was necessary.

Coverage Overlays

To summarize the process, ITS is using the data of a single transmitter analysis, produced by the ITS CSPM software and ArcGIS, and combining it with other single transmitter analyses. The process is then repeated until it produces an overlay for all unique combinations of two and three antennas. Using these overlay combinations, calculations of significant statistical characteristics of the coverage area can be determined. These characteristics include the available power standard deviation and mean over all or portions of the entire map.

Scenario Ranking

Additional statistics are under examination. ITS has developed metrics that use road and park overlays in order to consider signal availability within or near target areas. This allows for the examination of the park-only or road-only transmitted power availability. An enormous amount of data about each alternative communications solution is collected and used to create a weighting algorithm that considers each solution on its statistical and other merits. The outputs of the weighting algorithm can help to identify a "top 10 list" of solutions that satisfy both sound communications criteria and environmental and aesthetic criteria set forth by NPS, yielding the best possible options.

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Broadband Wireless Standards

<u>Outputs</u>

- Support for the 2009 Block Meetings of ITU-R Working Parties 3J, 3K, 3L, and 3M and the meeting of ITU-R Study Group 3.
- Support to ongoing efforts in various Correspondence Groups, formal and informal, conducting studies between meetings of the Working Parties.

Overview

Since the propagation of radio signals is rarely, if ever, affected by the presence of international frontiers, it is important that there be internationally recognized standards for radio propagation models which may be utilized for the purposes of bilateral and multilateral planning and coordination. As demand for spectrum has grown in recent years, the strategy of exclusive allocation of many bands has been replaced by the need to consider sharing of spectrum by different services. In response to this trend, standard radio propagation models are required to be applicable across widely disparate services as well, particularly when they are to be used to evaluate multilateral sharing proposals. Consequently, ITU-R Study Group 3 has been active in developing and revising these standards.

Standards Body Participation

In FY 2009, efforts on the Broadband Wireless Standards project were focused on preparations by and support of the U.S. Administration during the international meetings of ITU-R Study Group 3 (SG 3: radio-wave propagation) and Working Parties 3J (WP 3J: propagation fundamentals), 3K (WP 3K: point-to-area propagation), 3L (WP 3L: ionospheric propagation), and 3M (WP 3M: point-to-point and earth-space propagation). This round of international meetings was held at the ITU Headquarters in Geneva, Switzerland during the first two weeks of June 2009. Four ITS engineers participated in at least some portion of these meetings.

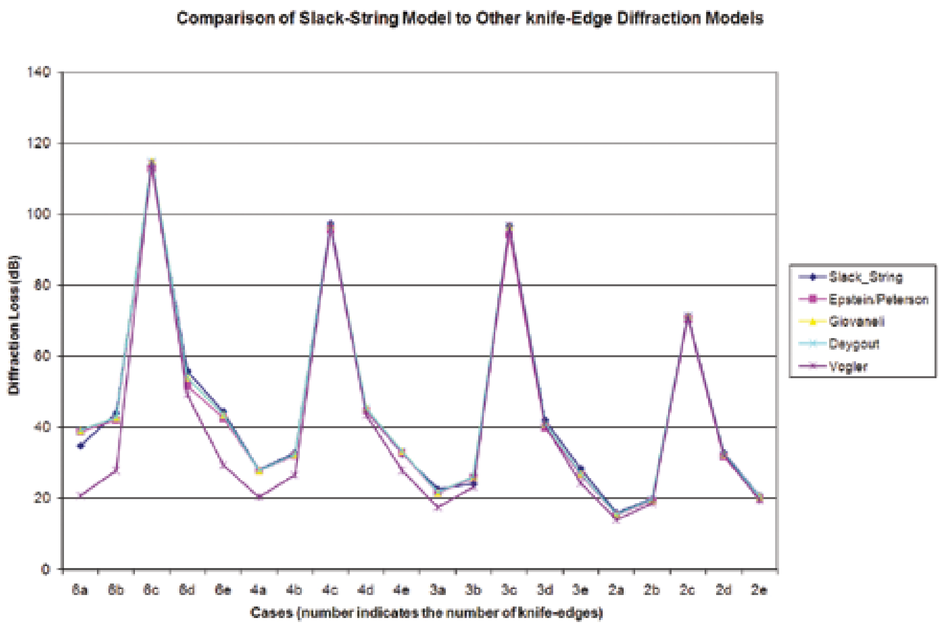
During the June 2008 Block Meetings in Boulder, Colorado, a special meeting of the Chairman of Study Group 3 and the four Working Party Chairmen led to a decision to designate WP 3J as the primary Working Party within Study Group 3 for evaluation of contributions related to diffraction, going forward. The primary reason for this decision was to provide a focal point for the studies involving diffraction in the different Working Parties and, in particular, to maintain alignment of any new or modified irregular terrain diffraction models, which might be adopted as elements of Recommendations ITU-R P.452 (WP 3M), P.526 (WP 3J) and P.1812 (WP 3K). For cases where a contribution or contributions proposed changes to the irregular terrain diffraction model element of one or more of these Recommendations, the Chairmen decided that joint meetings would be convened for the concerned subgroups/drafting groups of all of the affected Working Parties. An immediate consequence of the Chairmen's decision was that much of the ongoing work on diffraction being conducted in Subgroup 3K-1 was transferred to Subgroup 3J-4.

Among other things, this newly reformulated subgroup considered some issues that had been identified by a UK contribution with respect to the smooth-sphere diffraction model (Rec. ITU-R P.526). These observations led to an extensive examination of the model's fundamental derivation followed by a revision of this Recommendation's smooth-sphere diffraction method/description in 2009. The U.S. delegation, including members from ITS, was heavily involved in the formulation of these revisions.

Technical Contributions

U.S. preparatory work leading up to the 2009 meetings also involved basic studies on a new multi-edge method for approximating the total diffraction attenuation that occurs when multiple, separated obstacles obscure the direct ray between the two terminals at opposite ends of a terrestrial radio propagation path. This work was motivated by two introductory papers on the "slack string" method that were presented at the ISART/ClimDiff 2008 Conference. Although this method is inherently more computationally intensive than other well-known approximations that rely on the ordering of the individual edges' clearances, there were certain features of the slack string model/method that made it attractive for further study (see figure).

First, for single knife-edge paths, it yielded results very close to the standard theory for a wide range of clearance values. This feature would seem to be a prerequisite for any worthwhile approximation; in practice, many other methods experience difficulties for zero or negative clearances and so must rely on edge truncation schemes in order to avoid these difficulties. Second, the generalization of the method to the multi-edge problem depends on the length of the convex hull for that path, a quantity which is fixed by the individual edges' heights and separations, instead of the ordering of the individual edges' clearances with respect to one another. As a result, the method appeared to avoid certain discontinuities that have been observed with the other approximations. To the best of our knowledge, all rigorous formulations of the multi-edge problem are free of these discontinuities, so it was believed that a method that sought to approximate multi-edge diffraction, while avoiding discontinuities, would ultimately be more successful.



A comparison of the slack string multiple knife-edge approximation to other multiple knife-edge diffraction methods.

For an arbitrary sequence of multiple individual edges' heights and separations, a faithful implementation of the multi-edge, slack string method involves finding the maximum height of each individual edge (and each individual edge's minimum height, subject to a lower limit of the actual edge's height) with all inter-edge distances fixed and all other edge heights fixed, when the "new" convex hull length is increased relative to the original by the inverse of the wave number. In principle, this problem should admit a "closed" form solution to a constrained mini-max problem, but our (earliest) implementation relied on "brute-force " searches of the parameter space, given the obvious complexity of formulating the closed form solution. However, such a solution would make any implementation of this method much more computationally attractive to a general audience, but further quantification of its predictive accuracy is equally important. Given the limitations of our resources, we deemed our implementation adequate, and it culminated in a U.S. contribution to Working Party 3J on a comparison of the predictions of the novel, approximate, slack string method to the more analytically rigorous, but also much more computationally intensive, Fresnel-Kirchhoff solution for multiple knife-edge diffraction. Although there are other promising approaches to the multi-edge diffraction problem that should be considered, we continue to believe that further work on the "slack string" method is also warranted.

In particular, we believe that a closed form solution should be actively considered. Further work is underway to identify better methods to obtain mini-max solutions. Once these are obtained, this novel method may gain greater acceptance.

In parallel with this effort, additional work on multiple knife-edge diffraction continued. This effort involved further studies comparing predictions of various well-known approximations for multiple knife-edge diffraction to recent radio propagation measurements that ITS engineers obtained on paths on or near the Table Mountain Field Site and Radio Quiet Zone. These measurement sites have well defined terrain obstructions but are, otherwise, rural with low vehicular traffic densities and nearly uncluttered surrounding environments.

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Short-Range, Mobile-to-Mobile Propagation Model Development and Measurements

Outputs

- Analysis effort to develop propagation models for short-range mobile-to-mobile applications.
- Measurement program to support analysis effort and refine propagation models.

Overview

With the tremendous growth in demand for mobile wireless devices, it is necessary to address the problems of interference between existing and new radio spectrum users. The evolution of our communications infrastructure depends on these communication devices, and the successful operation of these devices in a crowded electromagnetic spectrum has a profound impact on our economy. An accurate and flexible radio propagation model is essential to meet the needs of the spectrum management and electromagnetic compatibility (EMC) analysis processes.

Propagation Model Refinement

During FY 2009, efforts on this project focused on leveraging analyses and measurements obtained in previous years as the bases for analytic and empirical models for short-range radio propagation. Specifically, a model was developed to treat open (i.e., uncluttered) environments based on the "Undisturbed Field" method, which is based on the solution of Maxwell's Equations for the electromagnetic field induced by a vertical electric dipole antenna above, and in close proximity to, a finitely conducting dielectric half-space (i.e., a plane earth). In addition, an empirical slope-intercept model for radio propagation in more complex (i.e., cluttered) environments, derived from narrow band measurements taken by ITS, was also developed.

Previous work had shown that the analytic "Undisturbed Field" model provided an excellent compromise between predictive fidelity and computational complexity in certain situations of practical interest, when and where the basic assumptions employed in the derivation of the model are met. The predictions obtained in the original report were obtained using the Numerical Electromagnetics Code (NEC), which implements a general-purpose method-of-moments solution of the thin-wire electric field integral equation that is derived from Maxwell's Equations. When a finitely-conducting dielectric half-space is present near the transmitting antenna, the electromagnetic field interaction, with this half-space, implies that the Sommerfeld integral should be evaluated, in order to obtain accurate predictions for paths having short distances and low antenna heights. In general, no closed-form solution of the Sommerfeld integral has been demonstrated, so it must be evaluated numerically, which can be tedious for many users. To avoid this difficulty, an implementation of the "Undisturbed Field" model was developed, which utilizes interpolations of tabulated values of basic transmission losses obtained from sampling the parameter space of frequencies, antenna heights, ground electrical constants, and path distances, which were previously calculated using NEC with the Sommerfeld option.

The "Undisturbed Field" model is not valid if the ground plane is not flat, relatively smooth (e.g., with undulations which are small compared to the wavelength at the frequency of interest), and homogeneous with respect to the electrical material properties of the ground and/or if there is substantial clutter (e.g., buildings, vehicles, etc.) on or near the path between the terminals. In particular, there are many urban propagation scenarios where one might not expect the model to be valid. Since urban environments are likely to have higher deployment densities of mobile-to-mobile devices and potential victim systems, it is desirable to have a model that can be used for predictions in these environments.

Measurement Program

In FY 2007 and FY 2008, ITS engineers collected radio propagation measurements in and around Denver and Boulder, Colorado, using a pseudo-mobile test procedure. ITS' transportable transmitter truck, the RSMS-3, was driven to a location and transmitting antennas were deployed nearby at a height of approximately 1 m above ground tethered to the RSMS-3 by RF cables. The ITS receiver van was then driven through the environment surrounding the transmitter location, and measurements of the signal strengths were recorded along with GPS derived positions (i.e., locations' latitudes and longitudes).

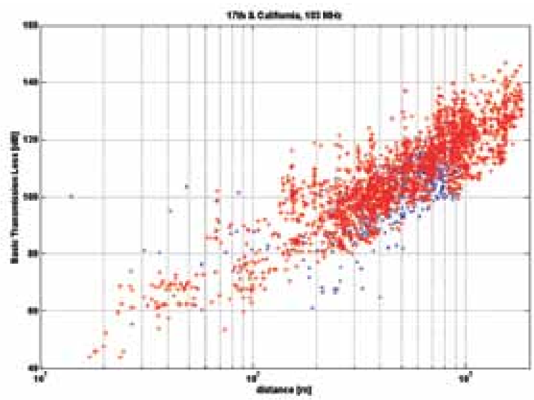

Figure 1. Comparison of wideband, x's, and narrowband, +'s, measured basic transmission losses in the dense urban high-rise region of downtown Denver, Colorado, at 183 MHz.

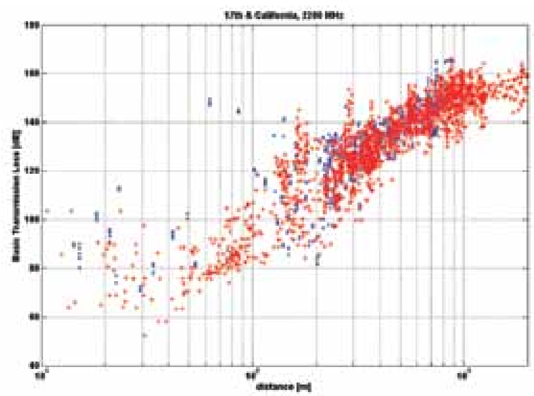

Figure 2. Comparison of wideband, x's, and narrowband, +'s, measured basic transmission losses in the dense urban high-rise region of downtown Denver, Colorado, at 2260 MHz.

For most of these locations, measurements were obtained at seven nominal frequencies: 183, 430, 915, 1350, 1602.5, 2260, and 5750 MHz. The rationale for making measurements at multiple frequencies was that it was expected, on physical grounds, that propagation characteristics would be frequency dependent. The raw signal-strength measurements and positions were subsequently post-processed to yield measured basic-transmission-loss values versus distance for each nominal frequency and transmitter location. As expected, these data exhibit the general trends of increasing basic transmission loss with distance and frequency.

These measured data constitute a rich store of propagation information that will likely serve as part of the basis for additional analytical work in the future. One feature of the measurements is that if the measurements from all transmitter locations are grouped together at each of the nominal frequencies, as opposed to grouping the data by each transmitter location and frequency separately, then the first approach yields much greater variability. This is not surprising if one expects that the propagation characteristics are correlated with (i.e., dependent on) not just the frequency and distance, but also the environment, and suggests that this last dependence should not be ignored.

In view of these observations, the empirical model, which is based on these measurements, attempts to mirror some of the general trends in the data. That is, in the case of the distance dependence, the model fits a power law via linear least-squares estimation. For the frequency and environmental dependences, where only discrete values are available, the model maintains separate categories. If a prediction at a frequency other than one of the nominal values is required, linear interpolation between the mean values and standard deviations is performed to estimate the basic transmission loss. In the current model's implementation, only single environmental categories are available.

Further enhancements to these models are anticipated, contingent largely on sponsor support and priorities. These enhancements include:

- seamlessly transitioning very short range predictions using the "Undisturbed Field" model with longer range predictions using the empirical model in complex environments,
- further refinements to the linear least squares estimates of the slope and intercept to generalize to dual slope and breakpoint formulations,
- more robust estimates of the empirical model's frequency dependence (i.e., non-linear interpolation),
- robust estimation across different environments, and
- additional measurement dataset integration when and where available.

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Ultra-Low Antenna Height Modeling and Measurements

OUTPUTS

- Unique radio-wave propagation models developed for use with ultra-low antenna heights and close-in distances.
- Undisturbed-Field Model, which can be used for antenna heights as low as zero meters (on the ground) and distances as close as 2 meters.
- Measurement program specifically tailored to collect data to verify the models developed for ultra-low antenna heights and close-in distances.

OVERVIEW

The Institute for Telecommunication Sciences was tasked by the U.S. Naval Research Laboratory to develop a radio-wave propagation model that could meet a unique set of requirements for use in scenarios with ultra-low antenna heights in the 0 to 3 meter range, at frequencies of 150 to 6000 MHz, and distances as close-in as 2 meters and extending out to 2 km. Radio-wave propagation models that could meet these stringent requirements did not exist. ITS developed the Undisturbed-Field Model to meet these requirements.

UNDISTURBED-FIELD MODEL

The Undisturbed-Field Model involves the calculation of the radio-wave propagation loss based on the undisturbed electric field as a function of antenna heights, distance, frequency, and the ground constants. The antenna gains are factored out to result in a basic transmission loss for use in the Undisturbed-Field Model. The undisturbed field is the electric field produced by a transmitter antenna at different distances and heights above ground without any field-disturbing factors in or around the receiver antenna location. In contrast, in a disturbed field an antenna located at the receiver site would disturb the electric field.

A detailed investigation of the differences between the Undisturbed-Field Model and the Disturbed-Field Model was performed. The investigation has determined that the difference between the propagation loss computed by the Undisturbed-Field Model and the Disturbed-Field Model is minimal. The Disturbed-Field Model is more exact, but it is more computationally intensive and difficult to calculate when compared to the relatively simple and fast computations obtained with the Undisturbed-Field Model. The Undisturbed-Field Model includes near-field effects, the complex two-ray model, antenna near-field and far-field response, and the surface wave. It can be used for antenna height ranges from 0 to 3 meters and frequencies from 150 MHz to 6000 MHz. Since this is a line-of-sight model, the ground is assumed to be flat with no irregular terrain over distances up to 30 meters. The Undisturbed-Field Model can be used for distances up to 2 km, but it is particularly applicable for near distances less than 30 meters. Work continues on refining the Undisturbed-Field Model.

ADDITIONAL PROPAGATION MODELS

Two other propagation models are still under development: an empirical model based on measured data and an analytical model that computes propagation loss over a concave path. An initial empirical model was developed that was based on the least squares fit to measured data using a single slope and intercept. The empirical model has been modified to accept additional measured data from the static vector network analyzer and dynamic spectrum analyzer measurements. Work continues on this model; current efforts are directed at fitting dual-slopes and breakpoints to the measured data.

A concave path model for low antenna heights was also developed from a theoretical approach using Fresnel reflection coefficients for multiple reflections from a continuous fit using linear segments to the curve that describes the terrain along the path. This model has demonstrated good agreement with measured data. Work continues on this model to generalize it to other path configurations.

MEASUREMENT PROGRAM

The measurement campaign focused on measurement configurations designed to use collected data to verify the analytical models developed for ultra-low antenna heights and close-in distances. Measurements were performed using many antenna heights from 0 to 3 m with distances of 2 m to 2 km. Two measurement systems were used: a static vector network analyzer using swept frequencies of 300 kHz

The two monopole-on-a-ground plane antennas are positioned at a height of zero meters for a close-in distance and ultra-low antenna height measurement (photograph by S. Carroll).

to 6000 MHz, and a dynamic spectrum analyzer using discrete frequencies from 150 MHz to 6000 MHz.

The static vector network analyzer measurement system has certain advantages over that used in other measurement techniques and provides data at frequencies within the operating bandwidth of the various antennas. The original raw data is recorded over a broad bandwidth, so that it can accurately be transformed into the time domain and time gated to remove interference, noise, unwanted reflections, and multipath. After time gating and further processing, the data is then transformed back into the frequency domain. Cable losses, antenna gains, calibration factors, transmitter power, and received power are taken into account to derive the basic transmission loss. The disadvantages of using this system include a maximum distance limitation of approximately 250 meters, and the data collection and measurement process is very time-consuming.

The dynamic spectrum analyzer measurement system can take measurements over much longer distances (up to 2 km and further), and is significantly faster at collecting data than the vector network analyzer system, but it also has its limitations when dealing with noise and multipath interference. ITS collected data over four different paths to compare against the model predictions: a flat path, a diffraction path, and two concave paths. Measurements were performed over seven frequencies from 150 MHz to 6000 MHz, many combinations of antenna heights from zero to 3 meters, and distances from about 2 meters to 2 km.

Data reduction and analysis is still ongoing for the measurements performed with both systems. Work on this project in FY 2010 will focus on obtaining more measurements in different scenarios, and further development of the analytical and empirical models for prediction of radio-wave propagation loss. The figure above is a photo of one of the test configurations used to measure propagation loss at ultra-low antenna heights.

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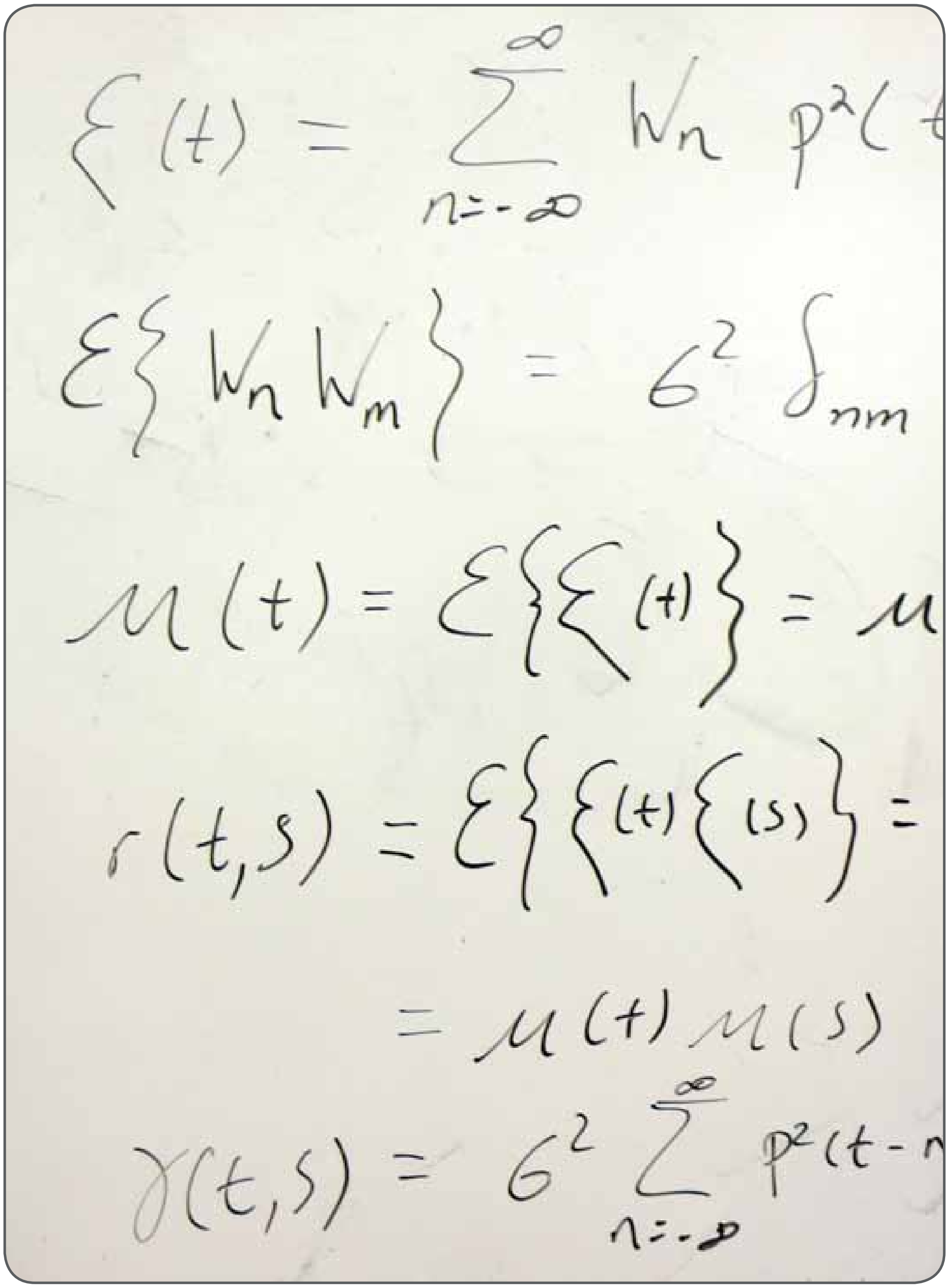

The ITS Telecommunications Theory Division fuses theory and application in spectrum engineering. Measurements verify theoretical predictions, but finite resources for tests and measurements leave theory as the necessary tool for the purpose of predicting the performance of any and all telecommunication systems (photograph by F.H. Sanders).

Telecommunications Theory

Telecommunications demands are increasing worldwide, requiring more infrastructure and, ultimately, more bandwidth. Wireline networks meet many of these needs, but some needs can only be met with wireless systems using radio spectrum. However, the radio spectrum is a limited resource. Increased demands therefore drive new radio technology development that promises to use spectrum more efficiently.

Radio spectrum management is responding to these changes by moving from traditional frequency-assignment methods toward self-controlled, interference-limited technologies. Historically rigid, service-by-service spectrum allocations (i.e., differentiation of band usage based on services such as broadcasting, radar, and mobile radio system in separate bands) are being replaced with allocations that expect more services to share individual radio bands. The successful development and implementation of sharing schemes depends upon the development of radio system capabilities to autonomously recognize and avoid interference.

Knowledge is required to understand the maximum interference level tolerance of radio systems. Such knowledge must focus on improvements in the performance of both new and existing networks. Tools to monitor the quality of audio and video information on communication channels also must be developed so that audio and video quality levels accurately adjust in real time, and achieve maximal quality with minimal bandwidth use.

To achieve these goals, the Institute performs telecommunications research, to understand and improve performance at the most fundamental levels of physics and engineering. Ongoing investigations include the following areas: broadband wireless systems performance in the presence of interference; new propagation models for short-range mobile radio systems; the effects of noise and interference as critical limiting factors for advanced communication systems; automated tools for assessing audio and video quality; and advanced spectrum sharing concepts such as dynamic frequency selection. Through technical publications, CRADAs, and interagency agreements, ITS transfers these research results to both the public and private sector, where the knowledge is transformed into better telecommunications, new and better products, and new opportunities for economic development.

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Areas of Emphasis

Audio Quality Research The Institute conducts research and development leading to standardization and industry implementation of perception-based, technology-independent quality measures for voice and other audio communication systems. Projects are funded by NTIA.

Effects of the Channel on Radio System Performance The Institute, a recognized leader in radio channel measurement and modeling, is researching the effects of interference and noise on the performance of radio receivers and networks. Current work is focused on the effects of noise and interference as limiting factors in system performance. The project is funded by NTIA.

Time-Domain Pulsed Measurements of the NASA Space Power Facility NASA is developing a manned spacecraft. ITS performed theoretical analyses and measurements of radio-wave behavior inside a NASA vacuum chamber in which the spacecraft will be tested. The purpose of the work, funded by NASA, is to ensure the validity of results from electromagnetic field testing on the spacecraft in the chamber.

Interference Effect Tests and Measurements on Weather Radars In response to interference problems from non-radar systems that share spectrum bands with weather radars, ITS has performed an extensive set of analyses and measurements jointly with NTIA's Office of Spectrum Management. 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. These projects are funded by NTIA.

Broadband Wireless Research ITS develops techniques for assessing the performance of broadband wireless systems in real-world radio propagation environments. This project is 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.

Overview

Digital encoding and transmission of speech signals enable many telecommunications services including voice over Internet protocol (VoIP), cellular telephone, voice messaging, and automatic voice recognition. Similarly, general audio signals including music, voices, environmental sounds, and sound effects can be digitally encoded and transmitted. This has enabled multi-channel satellite and terrestrial digital audio broadcasting services, recorded entertainment products, and Internet digital audio streaming services.

This technology is maturing, but numerous challenges remain. The goal of efficient, robust, and flexible speech and audio signal encoding at reduced bitrates while maintaining good fidelity is encumbered by a complex set of trade-offs. The most apparent of these is the trade-off between signal quality and encoded bitrate. But both of these properties are linked to design choices regarding robustness (to transmission errors and losses) and adaptability (to different signal classes, bandwidths, quality levels, coding rates, or robustness levels). Finally, all of these can influence coding and transmission delay as well as algorithm complexity. Ongoing research efforts continue to lead to innovations in these areas including new understandings of the relationships between them. Yet joint optimization with respect to these factors remains an elusive goal.

Figure 1. A sampling of resources used for audio quality research (photograph by A. Catellier).

The ITS Audio Quality Research Program contributes to these advances. The Program identifies, develops, and characterizes innovations for speech and audio coding and transmission that may increase quality, robustness, or flexibility, or that may decrease bit-rate, delay, or complexity. In addition, the program seeks to advance tools and techniques for optimizing the trade-offs between these factors. To optimize, one must be able to quantify. The quantification of speech and audio quality is a significant challenge as it involves the interplay between technology factors, human perception, and human judgment. The ultimate goal for program efforts is more reliable and efficient telecommunications and broadcasting services with improved speech and audio quality. A sampling of the resources used in this work is shown in Figure 1.

Subjective testing is the most direct means for assessing speech or audio quality. This involves listeners that evaluate recordings in a controlled laboratory setting, like the one shown in Figure 2. Great care must be taken to prepare an appropriate set of recordings and to configure the desired laboratory environment. Then 16 to 32 listeners are recruited to participate in the testing, with each spending about one hour on this effort. Overall, the entire process can be quite time-consuming and costly and methods for combating this are very desirable.

Measurements of Speech Quality

In FY 2009 Program staff developed a highly efficient way to use subjective testing to identify optimizing parameter values for speech or audio coding and transmission. The technique, called Gradient Ascent Subjective Testing, combines classical gradient ascent search methods with paired-comparison subjective testing. Staff designed a proof-of-concept experiment that demonstrated that the technique provides significant time (and thus cost) savings when compared to the conventional approach. Staff documented the work in a technical paper that was presented to the research community at an international workshop and this paper received the "Best Paper" award at that workshop.

Program staff were asked to characterize the performance of specific low bit-rate speech coders when bit errors are present in the transmission channel between encoder and decoder. Staff applied a variant of the Gradient Ascent Subjective Testing algorithm described above to efficiently locate bit error rates that gave a specified reference speech quality level.

Staff also designed, implemented, and analyzed a subjective test to quantify listener perceptions of abrupt and gradual transitions between narrowband speech (nominally 4 kHz) and wideband speech (nominally 7 kHz). The purpose of the work was to evaluate the users' perception of future telecommunication systems that could adaptively provide either bandwidth depending on network conditions. Listeners clearly prefer wideband speech to narrowband speech since it has a fuller, more realistic sound and slightly higher intelligibility. However, the experiment also revealed that transitions from narrowband to wideband speech are perceived as significant impairments by many listeners, so successful telecommunication services will need to use caution and care when presenting such transitions to users.

Speech Coding

In other FY 2009 work, program staff developed and analyzed a technique that enhances the quality of speech produced by a class of existing speech coders. The improvement comes from better reproduction of speech onsets. Onsets are difficult to encode properly and they are critical to speech intelligibility. In addition, staff continued with efforts to losslessly encode telecommunications quality speech. New predictive coding and entropy coding techniques were applied and analyzed for use in this specific encoding application.

Additional Work

Throughout FY 2009, program staff continued with additional speech and audio quality testing using both objective and subjective techniques. These tests support both this program and other ITS programs. Some laboratory upgrades were performed throughout the year. Staff continued to transfer program results to industry, Government, and academia by means of technical publications, lectures, laboratory demonstrations, and poster presentations. Staff also completed a significant number of peer review and associate editor functions for technical papers on speech and audio coding, transmission, and quality assessment submitted to journals, conferences, and workshops. Program staff supported telecommunications standards development through research efforts and technical exchanges. Program publications, technical information, and other program results are available at http://www.its.bldrdoc.gov/audio.

Figure 2. Interior of a subjective testing laboratory (photograph by A. Catellier).

Recent Publications

S.D. Voran and A.A. Catellier, "Gradient ascent paired-comparison subjective quality testing," *Proc. of the IEEE First International Workshop on Quality of Multimedia Experience (QoMEX)*, San Diego, Jul. 2009.

A.A. Catellier and S.D. Voran, "Relationships between intelligibility, speaker identification, and the detection of dramatized urgency," NTIA Technical Report TR-09-459, Nov. 2008.

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Effects of the Channel on Radio System Performance

OUTPUTS

- Interference susceptibility analysis.
- Translation of channel measurements to receiver performance metrics.

OVERVIEW

Telecommunications play a vital role in providing services deemed essential for modern life. Many of these services use radio links composed of a transmitter and receiver, i.e., the radio system, and the channel separating the two. The channel is often the primary impediment to fast and reliable radio system performance. Understanding the channel and the effects of the channel on radio system performance is crucial to the advancement and regulation of telecommunications.

The channel degrades radio system performance by introducing undesired signals and multipath. Multipath is due to reflection, diffraction, and scattering propagation phenomena supported by the channel media, which can be as diverse as the earth's ionosphere or an urban landscape. Undesired signals include natural noise created by phenomena such as lightning, man-made noise generated by electrical devices, and signals from other radio systems.

Multipath is, in essence, channel filtering, which can potentially cause signal fading and intersymbol interference. Undesired signals reduce signal power margins. Both cause increased numbers of transmission errors whose statistics are used to quantify the effect of the radio channel on radio system performance. These statistics can be as simple as error rate or as complex as mean time between errors.

This project requires a broad spectrum of tasks. The fundamental task is to collect radio link error statistics either by software simulation, hardware measurements, or analytic modeling. Supporting tasks include developing simulation or measurement procedures, identifying important performance metrics, characterizing channels, correlating performance metrics with channel characteristics, and analyzing experimental uncertainty.

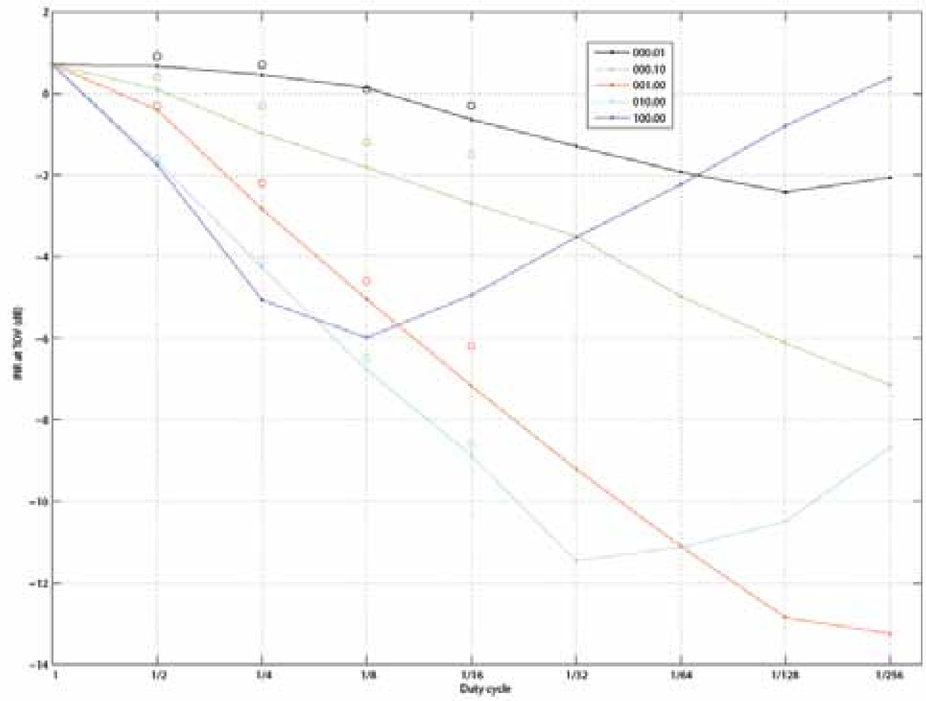
Results from our work are useful to radio system designers and radio spectrum managers. Radio system designers often want channel measurements reported directly in terms of their effect on radio system performance. As an example, an engineer studying the effect of multipath on a radio system might find bit error rate more meaningful than root mean square delay spread. Radio spectrum managers need to be able to evaluate the susceptibility of legacy receivers to signals from other radio systems. This need has become more pressing as spectrum managers seek to alleviate spectrum scarcity through novel spectrum sharing techniques.

CURRENT WORK

Previously, ITS conducted extensive hardware tests on the effect of undesired gated Gaussian noise on a satellite broadcast digital television (DTV) receiver. Due to hardware limitations, the effect of the gated Gaussian noise on a particular signal processing stage within the receiver could not be determined. ITS addressed this deficiency by developing a software simulated radio link model which can evaluate the effect of the channel on an isolated signal processing stage.

During FY 2009 this model was used to evaluate the effect of the gated Gaussian noise parameters such as duty cycle and on-time on the Viterbi decoder which is a key signal processing stage in the DTV receiver. The effect was measured in terms of the interfering signal to noise power ratio (INR) at the threshold of visibility (TOV) where degradation is first perceived, i.e., INR_{TOV}. The TOV is defined in terms of error rate.

The figure shows the results of this work where the TOV is 1×10^{-3} bit error rate for the software simulated Viterbi detector and 1×10^{-4} MPEG segment error rate for the DTV hardware measurements. The circles represent results of the hardware measurements with the entire DTV signal processing chain which includes de-interleaving and Reed Solomon block decoding in addition to Viterbi decoding while the lines represent results of the software simulated Viterbi decoder alone. The close agreement indicates that the interference observed in the hardware measurements was due mainly to the Viterbi decoder.



INR_{TOV} for various gated Gaussian noise duty-cycles and on-times for Viterbi detector simulation and radio equipment hardware measurements.

During the course of the research, we also became interested in understanding why there was a sharp reversal in susceptibility for the 10 and 100 microsecond on-times as duty cycle decreased. Extensive analysis suggests that this is due to the on-time exceeding the time period over which the Viterbi decoder performs its computations, i.e., the time period corresponding to the finite Viterbi decoder trellis length. Effects such as these are important for spectrum engineers to consider when specifying conditions for testing interference protection criteria (IPC).

Corresponding development of an analytic expression of the effect of gated Gaussian noise on Viterbi decoding was also undertaken during FY 2009. Theoretical studies such as this are crucial for developing an understanding of the interference problem. This study revealed that performance is not dependent on gated Gaussian noise on-time as the simulated and measured results were. This discrepancy was found to be due to the analytic expression's assumption of an infinite trellis length. Further research will be directed toward determining if tractable solutions are possible for finite trellis lengths.

Significant progress was also made toward directing results of our work towards the creation of meaningful IPC. ITS engineers performed a detailed review of the latest version of the Communications Degradation Handbook used by the NTIA Office of Spectrum Management to establish IPC. After the review, a new methodology for determining IPC was developed which integrated ideas presented in the Handbook with those developed during the course of our work.

Finally, an analysis of the error inherent to measuring power spectral densities with modern digital spectrum analyzers was performed. This work is essential for understanding the accuracy of Radio Spectrum Engineering Criteria measurements used by spectrum engineers to evaluate potential interference. A report describing this work is currently in review.

Recent Publications

R. A. Dalke, "Statistical considerations for noise and interference measurements," NTIA Report TR-09-458, Nov. 2008.

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Time-Domain Pulsed Measurements of the NASA Space Power Facility

Outputs

- A direct-pulse measurement system based on simple instrumentation: UWB pulse generator and 12 GHz bandwidth real-time oscilloscope.
- A system ideal for highly-reverberant environments like that encountered at the NASA Space-Power Facility.
- Measurements of insertion loss and chamber energy decay times.

Overview

In the near future, NASA will begin tests on the next-generation, manned Orion space vehicle at the Space Power Facility (SPF) at the Plum Brook Station near Sandusky, Ohio. The test campaign will include electromagnetic environmental effects (E3) tests. E3 testing will be performed within the SPF vacuum chamber, which is an all-aluminum, hemisphere-on-cylinder vessel 100 feet in diameter and 122 feet high (Figure 1). Radiofrequency test equipment will be used around the periphery of the assembled Orion vehicle to conduct system-level radiated susceptibility testing. The unique shape, large volume, and high inner-surface reflectivity of the SPF vacuum chamber will create a distinctive electromagnetic environment within the chamber. It is necessary to thoroughly understand the electromagnetic propagation and reverberation characteristics in the chamber to minimize risk to the vehicle under test. Specifically, NASA seeks to understand and control the electric field strength throughout the vacuum chamber, and minimize regions of localized high radio frequency (RF) intensity that could cause overexposure of the Orion vehicle to electromagnetic fields.

Direct-Pulse System

At the request of the NASA Glenn Research Center, researchers at ITS have developed a system to perform ultra-wideband (UWB) propagation and loss measurements using a direct pulse measurement system, consisting of an impulse generator, 12 GHz bandwidth high-speed oscilloscope, trigger generator, and precision microwave cables. The system transmits ultra-wideband impulses (20 MHz-1.5 GHz) into the SPF chamber, which undergo multiple reflections from the chamber boundaries and are received remotely by a high-speed oscilloscope that is connected to a receiving antenna (Figure 2). The chamber was scanned over two planes, parallel to the chamber floor, with the transmitting antenna fixed at two locations; and along a vertical line extending from 50-110' above the center of the chamber floor. In all, 138 transmission measurements were performed using three different sets of antennas.

Measurement Data

The received waveform data are processed to yield two highly useful quantities:

1. insertion gain
2. energy decay times.

These parameters yield important information about the average and peak electric-field levels that occur in the chamber volume and the electromagnetic loss mechanisms in the chamber itself. Figures 3 and 4 show insertion loss and energy-decay time characteristics obtained over two horizontal scan planes. The results are plotted for three pairs of antennas: biconicals (green), discones (red), and log-periodics (blue). The results highlight several interesting chamber characteristics. First, the clustering of the curves indicates that the chamber has uniform and diffuse electromagnetic fields—a characteristic necessary for effective E3 testing in this chamber. The tight clustering of the decay curves also indicates good electric-field uniformity. The energy-decay curves also tell us much about the chamber loss mechanisms. At low frequencies, the antenna loading dominates chamber losses, whereas at high frequencies, wall losses and surface/volumetric losses are significantly more common.

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Figure 1. The SPF vacuum chamber with typical test article. Note the large access door and buttresses in front of and behind the rocket.

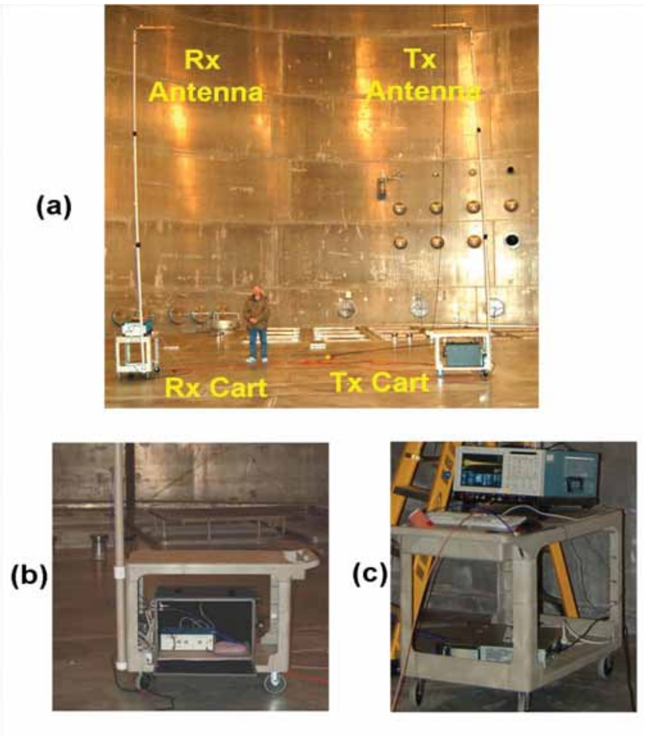

Figure 2. (a) Setup for chamber measurements. (b) Pulse generator inside a shielded box. (c) Oscilloscope mounted on cart.

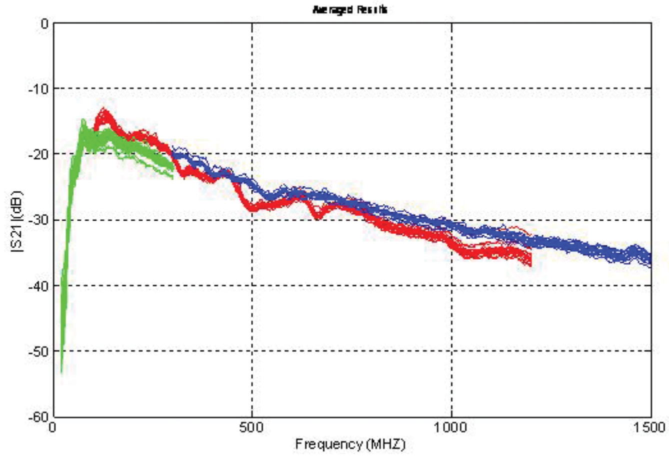

Figure 3. Frequency-averaged (BW=10 MHz) insertion loss results for 3 antenna types: green (biconical), red (discone), and blue (log-periodic).

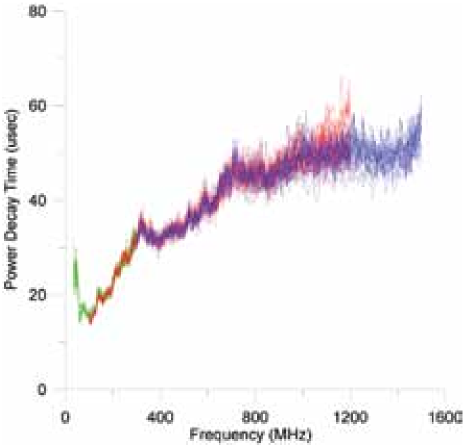

Figure 4. Energy-decay time results obtained over all of the horizontal scans for three antenna types (20 positions). Green (biconical), red (discone), and blue (log-periodic).

Interference Effect Tests and Measurements on Weather Radars

Outputs

- Predictions of the effects of interference from non-radar systems with weather radars.
- Measurements of interference characteristics at weather radar sites and identification of interference sources across the U.S.
- Controlled engineering tests to determine the thresholds at which interference occurs to weather radars.
- Development of new dynamic frequency selection (DFS) test-and-certification protocols to prevent future interference to weather radars from DFS wireless transmitters.

Overview

In FY 2009, a Federal agency contacted NTIA regarding interference that was occurring at weather radar sites across the United States. The interference was a serious problem because these radars are used for detecting potentially dangerous weather patterns. The agency requested NTIA's assistance in identifying the interference sources and developing technical solutions to the interference problem.

Interference Source Identification

A joint NTIA team of engineers from ITS and the Office of Spectrum Management (OSM) traveled to the most-affected location. The team set up measurement equipment at that radar installation and performed measurements at several points inside the weather radar receiver. The interference was quickly identified as originating from unlicensed wireless communication devices that were supposed to share the band with the radars on a not-to-interfere basis. The wireless communication devices were supposed to be equipped with dynamic frequency selection (DFS) technology that causes them to detect radar emissions and avoid radar frequencies.

A number of the devices that were causing interference were examined by the NTIA team at a number of locations across the metropolitan area around the weather radar. The manufacturers and model numbers of the devices were recorded, and examples of the devices were procured by NTIA. Those devices were tested for DFS performance at the ITS laboratory in Boulder. Some devices did not detect radar signals; others detected DFS-certification radar pulses but not actual weather radar pulses; and yet others detected weather radar pulses and changed frequency, but not necessarily with enough of a frequency change to preclude interference to weather radar receivers.

Interference Threshold Tests

With this information, NTIA engineers from ITS and OSM performed a set of follow-up tests and measurements at a weather radar engineering development center, consistent with existing NTIA procedures.[1] Several representative, unlicensed communication devices were operated in close proximity (2 miles distance) to the engineering weather radar. The behaviors that had been documented at the field location and at the laboratory in Boulder were replicated with the engineering radar (see figure). The interference effects that had been observed at the original field location were replicated. Other devices that had performed well at the Boulder lab were verified as working properly to detect and avoid the engineering radar emissions. A device that had not originally detected radar emissions was shown to detect the radar signal when operated with modified DFS software.

Results

The conclusion of the work included two key results: the exact interference power level where the radar was affected was measured and documented, and new DFS test-and-certification protocols were developed for assuring that certification would guarantee that certified devices would detect and avoid radar emissions and frequencies in the future. As of the end of FY 2009, NTIA was working with other Federal agencies and industry to implement the new DFS certification protocols to prevent any further interference to weather radars.

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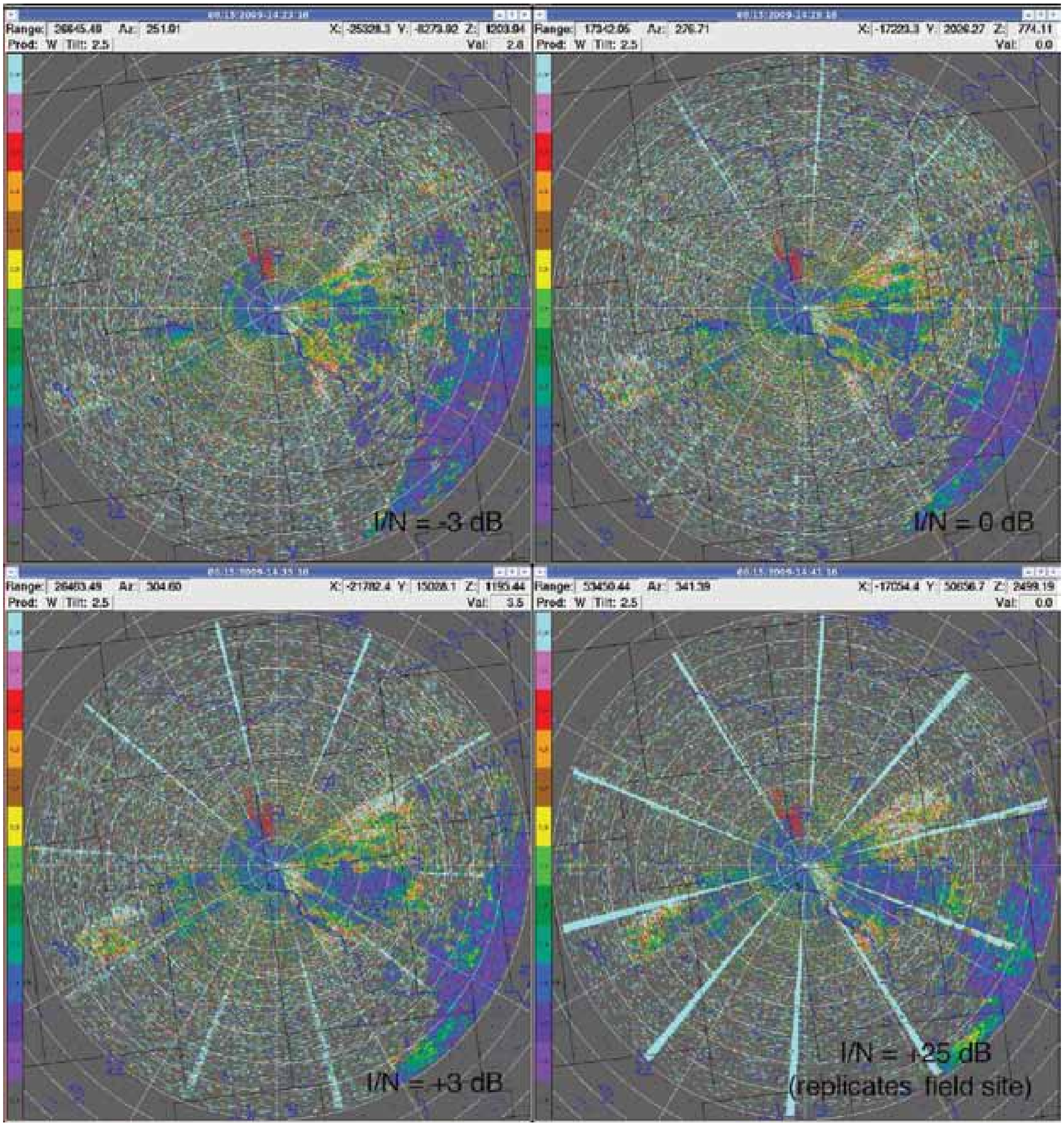
1. F.H. Sanders, et al., "Effects of RF interference on radar receivers," NTIA Technical Report TR-06-444, Sep. 2006.



Interference effects on a weather radar display. The bright lines, called strobes, are caused by test signals that replicate emissions from unlicensed devices. Interference effects occur when the emissions are 3 dB below the radar receiver noise floor. Actual interference at field locations has been documented by NTIA at 25 dB above the radar noise floor (bottom right).

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.
- The development, advancement, and maintenance of a national objective and subjective digital video quality measurement laboratory.

Overview

Service providers and end-users need objective metrics for quantifying digital video system performance (e.g., direct broadcast satellite, digital television, high definition television, video teleconferencing, telemedicine, internet, and cell phone video) for system performance specification, competing service offerings comparison, network maintenance, and limited network resource optimization. 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 increased quality of service, which benefits all end-users and service providers.

Technical Solutions

In order for digital video quality measurements to be accurate, they 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 overcome this limitation 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 RR or "Reduced Reference" measurements) have received four U.S. patents, been adopted as the North American Standard for measuring digital video quality (ANSI T1.801.03 2003), been included in three International Recommendations (ITU-T Recommendation J.144, J.244, and ITU-R Recommendation BT.1683), and are currently being used by hundreds of individuals and organizations worldwide.

During FY 2009, ITS participated as a proponent in the Reduced Reference TV (RRTV) validation tests that were conducted within the Video Quality Expert Group (VQEG). As a result of the excellent objective-to-subjective correlation results for the ITS-developed metric, it was included in a new ITU-T Recommendation (J.249). ITS also worked as part of the Independent Laboratory Group (ILG) within the Video Quality Experts Group (VQEG) to validate objective video quality models for mobile/PDA internet communication services and High Definition TV (HDTV) systems. To support this VQEG work, ITS developed a new Peak Signal-to-Noise Ratio (PSNR) algorithm that automatically determines the highest possible PSNR value for a given video sequence over the range of spatial shifts, temporal shifts, and changes in gain/level offset. The PSNR algorithm was standardized as a new ITU-T Recommendation (J.340).

Digital Video Quality Measurement Tools

To facilitate the transfer of ITS-developed video quality metrics (VQMs) into the private sector, ITS has developed and maintains multiple software tools for 32-bit and 64-bit operating systems. 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 first tool, called Command VQM (CVQM), provides a simple command line interface for processing (i.e., calibration and video quality measurements) a pair of video files that have been captured from the source and destination ends of a video transmission system.

The second tool, called Batch VQM (BVQM), allows the user to perform Graphical User Interface (GUI) based batch mode processing of many captured video streams, or files. The third tool, called In-Service VQM (IVQM), requires two PCs, one located at the source end and the other located at the destination end of a video transmission system. The two PCs communicate their reduced reference features via the Internet, producing in-service, end-to-end video quality monitoring results. Three other software tools extract additional performance metrics from digital video streams: PSNR, Fraction of Dropped Frames (FDF), and Variable Frame Delays (VFD). Source code and executable binaries of these tools are available royalty free to all interested parties.

Digital video transmission systems can cause disruptive pauses in the video presentation, after which the video may continue with or without skipping video frames. This time varying delay of the output (or processed) video frames can present a challenge for video quality measurement systems. In FY 2009, ITS developed a new algorithm for estimating variable video delays that includes sophisticated causality processing of the Mean Squared Errors (MSEs) between processed frames and original frames. The causality processing improves the robustness of the delay estimates, allowing them to be utilized by a quality measurement system as a calibration step before computing the quality measurement.

Figure 1 gives an example plot of the MSE function for one processed video frame when it is compared with a set of original video frames. The original frame with the smallest MSE (i.e., closest match to the processed frame) is shown as a red circle on the plot. Figure 1 gives one slice at processed frame 50 of the three dimensional MSE function shown in Figure 2. In Figure 2, higher MSE values are hotter colors (with red being the highest) while lower MSE values are cooler colors (with blue being the lowest), except for the best matching original frame, which is shown as a red circle as in Figure 1. NTIA Technical Memorandum TM-10-463 fully documents the new algorithm.

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

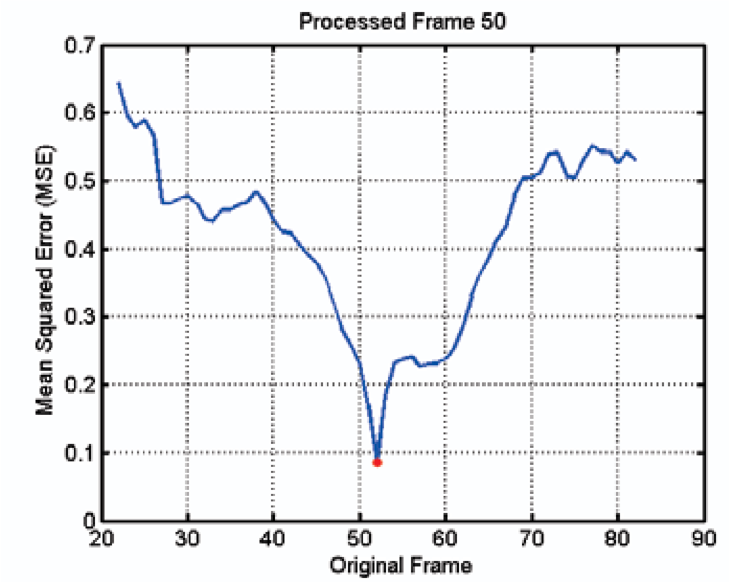


Figure 1. MSE function for one processed frame.

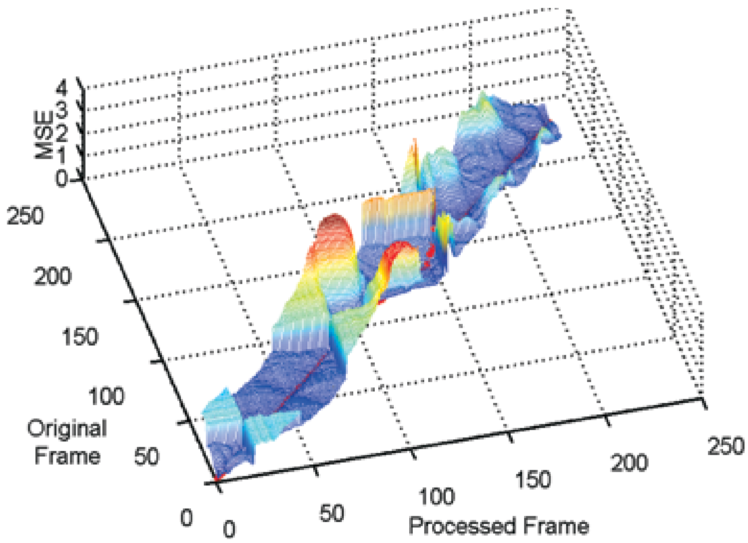


Figure 2. MSE function for many processed frames.

Recent Publications

S. Wolf, "A full reference (FR) method using causality processing for estimating variable video delays," NTIA Report TM-10-463, Oct. 2009.

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Broadband Wireless Research

Outputs

- Extensive numerical modeling of propagation measurement scenarios using COTS EMC antennas.
- Simulations show dramatic improvement in range resolution.

Overview

The proliferation of short-range wireless devices highlights the need for high-resolution channel sounding. A new technique is under development to provide high-resolution short-range propagation measurements using ordinary commercial, off-the-shelf (COTS) antennas. ITS researchers are investigating the use of COTS EMC antennas such as biconical dipoles, log-periodic dipole arrays (LPDA), dipoles, and dual-ridge horns to perform high-resolution, time-domain channel sounding measurements. The answer to this question is not simple. First of all, these antenna types are not optimized for time-domain measurements, and they have temporally-extended impulse responses that prevent the separation and identification of reflections from nearby objects. Thus, ITS somehow needed to reduce the duration of the antenna impulse response to obtain a high-resolution capability, which enables separation of these events.

Modeling and Simulations

One way to reduce the impulse response duration is to use a combination of a free-space or quasi-free-space reference and signal processing. A free-space reference is a transmission measurement between a pair of antennas without reflections from nearby reflectors such as ground, buildings, or trees. Recent advances in EMC antenna metrology have shown that it is possible to obtain a quasi-free-space transmission over an open-area test site, using a combination of a vector network analyzer, stepped-frequency measurements, low-reflectivity towers, and signal processing that uses time gating. Given the stability and precision of VNA measurements, we might be able to use the free-space reference data in combination with in-situ propagation measurements and thereby obtain high-resolution waveforms and extract useful channel parameters such as delay spread and basic transmission loss.

In order to simulate the proposed measurement procedure, a public-domain method-of-moments code (NEC-2) is used to simulate a two-antenna transmission in both free space and over a metallic ground plane (Figure 1). We simulate a VNA measurement by stepping the transmitted frequency over a wide range and compute the magnitude and phase of the resulting s-parameters. The resulting transmission data are post-processed to produce high-resolution time-domain waveforms. Three antenna types were investigated (Figure 2):

1. biconical dipoles,
2. dipoles,
3. log-periodic dipole arrays.

The simulations look very promising and demonstrate that high-resolution time-domain waveforms can be obtained using all three antenna types (Figures 3-4).

Research is currently underway to make the transition from simulations to actual measurements. We are using a combination of a COTS vector network analyzer, an analog optical link, and dielectric masts to implement this approach. We have found that free-space references can be obtained at modest heights above ground (7 m) using time-gating techniques. We are observing significant reductions in antenna response times. The results to date look quite promising, and we will publish them in the near future.

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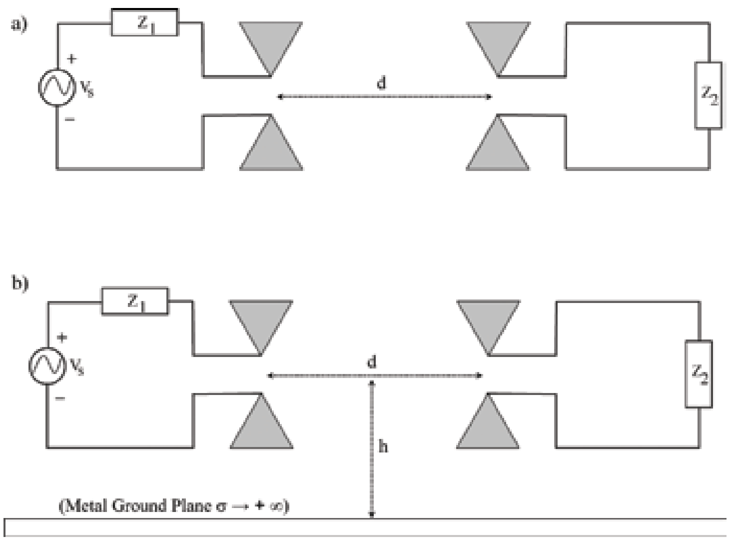

Figure 1. Two-antenna setups: a) Free-space environment, b) over a conducting ground plane.

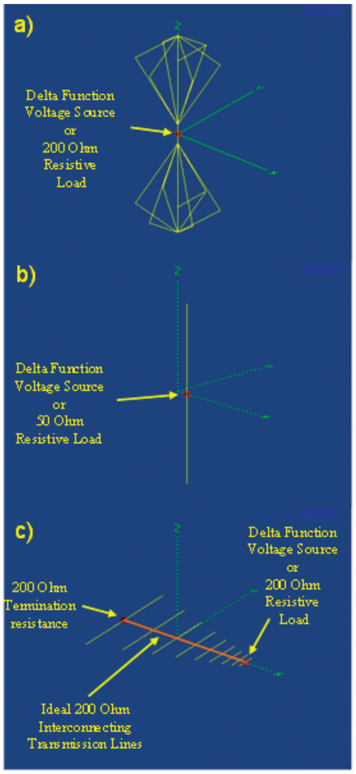

Figure 2. NEC MoM models for a) Biconical antenna b) dipole antenna, and c) log-periodic dipole array.

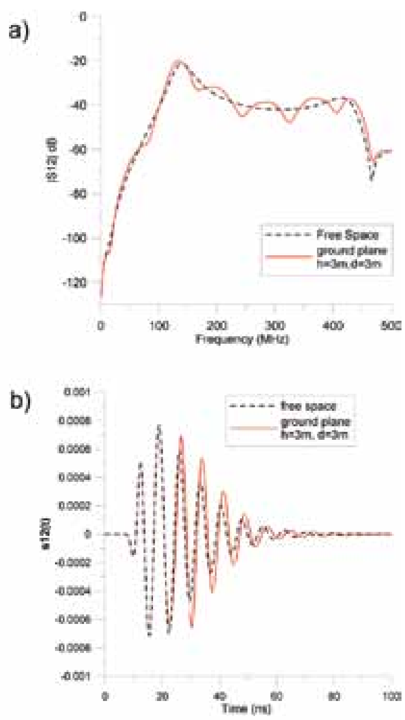

Figure 3. a) Frequency-domain transmission for a dipole in free space and over a ground plane b) corresponding time-domain responses.

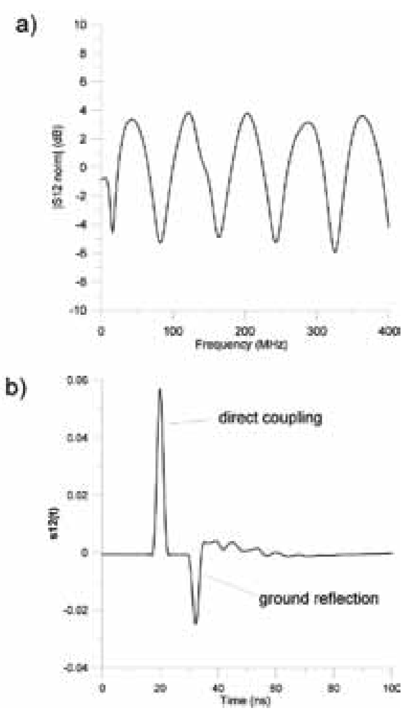

Figure 4. Enhanced results for a dipole over a ground plane in a) the frequency domain, and b) the time domain. Note the separation of the direct antenna coupling and the ground reflection.

Technology Transfer to Industry and Academia

OUTPUTS

- Cooperative research and development agreements with private companies and universities to perform telecommunications research and/or to use the Table Mountain Field Site for telecommunications-related research.

OVERVIEW

Technology transfer is the process by which existing knowledge, facilities, or capabilities developed under Federal research and development (R&D) funding are utilized to fulfill public and private needs. This definition was developed by the Federal Laboratory Consortium for Technology Transfer (FLC), a network of over 700 Federal laboratories including ITS, and the only government-wide forum for technology transfer. Organized in 1974, the FLC promotes and facilitates technical cooperation among Federal laboratories, industry, academia, and State and local governments.

CRADAs

ITS participates in technology transfer and commercialization efforts in a number of ways: through fostering cooperative telecommunications research with industry where benefits can directly facilitate U.S. competitiveness and market opportunities, through making the Table Mountain Field Site available for research by industry and academia, and also through distribution of our software. The Federal Technology Transfer Act of 1986 (FTTA), as amended, allows Federal laboratories to enter into cooperative research agreements with private industry, universities, and other interested parties. Under this Act, an agency can implement a cooperative research and development agreement (CRADA) 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 has participated for a number of years in CRADAs with non-Federal organizations to design, develop, test, and evaluate advanced telecommunication concepts. 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. 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.

TABLE MOUNTAIN FIELD SITE

While ITS often participates in CRADAs that involve performing measurements for an organization (thus transferring the Institute's knowledge and expertise), another common form of technology transfer utilized by ITS is to make the Table Mountain Field Site available for telecommunications research. Federal facilities such as Table Mountain often contain resources (or, as in this case, are resources) otherwise unavailable to the general public. Figures 1 and 2 are examples of the results of some of the work performed through CRADAs. Active Table Mountain CRADAs in FY 2009 and publications resulting from them are described on page 11 in the Spectrum and Propagation Measurements section.

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 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, ITS will continue to pursue technology transfer to the private sector through CRADAs and thereby contribute to the rapid commercialization of these new technologies.

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Figure 1. Results of outdoor jeep imaging tests. This shows the successful 3D imaging of a jeep at a standoff range of 0.5 km using a single channel receiver (images courtesy of Northrup Grumman).

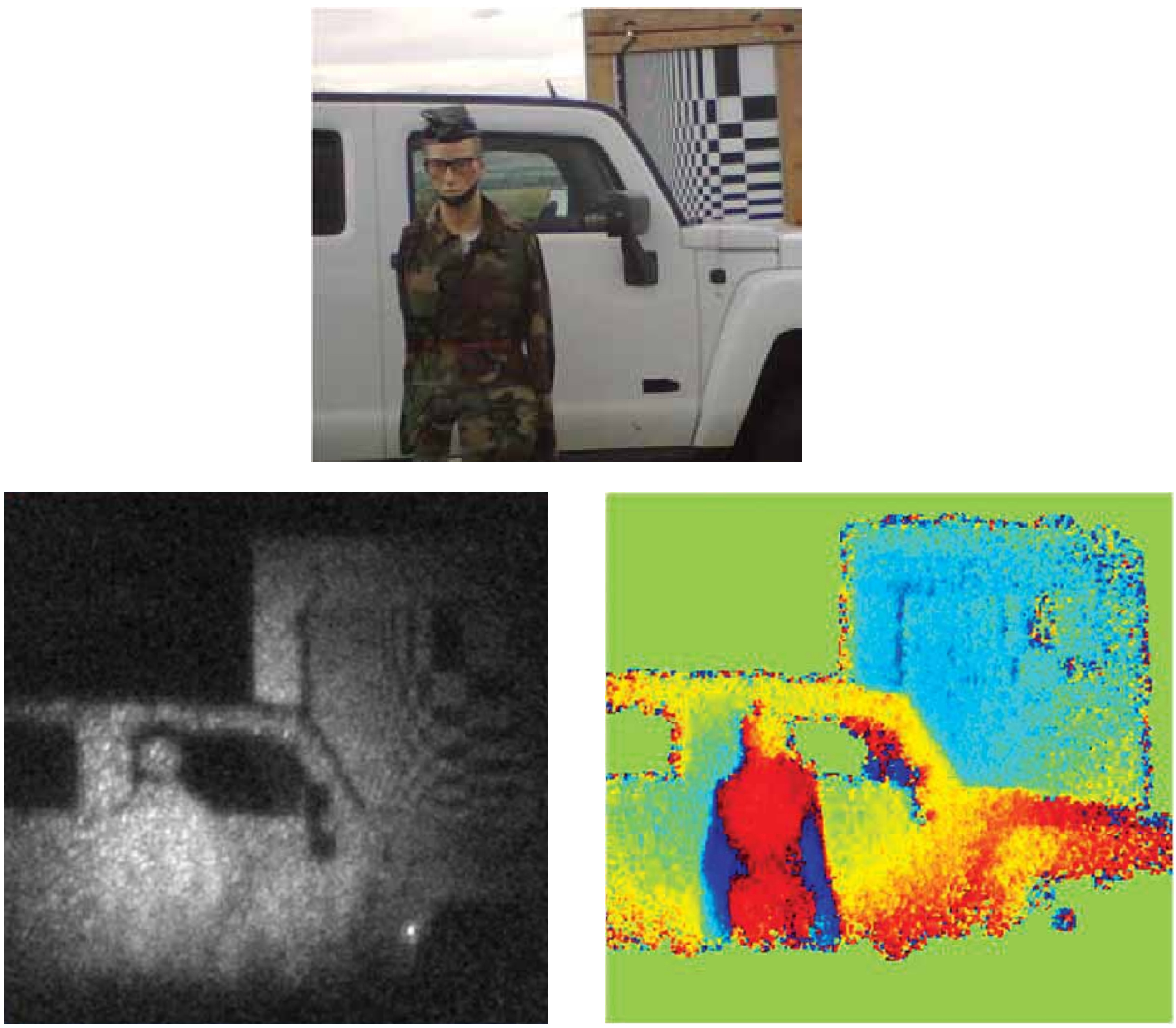

Figure 2. Example target used for 3D holographic-imaging done at 1.5 km (top). 2D (bottom left) and 3D (bottom right) images illustrating the depth information in the 3D imaging. The depth information is color-coded with red being closest and blue being 10 cm further away (images courtesy of Northrup Grumman).

ITU-R Standards Activities

OUTPUTS

- Technical support for U.S. Administration activities in ITU-R Study Group 3 and Working Parties 3J, 3K, 3L, 3M, 5B, 5D, and 6C.
- Ongoing measurements of interference from/to radar systems and communications systems.

OVERVIEW

Success in worldwide telecommunications markets, as well as effective and compatible use of telecommunications technologies both domestically and abroad, is vital to the long-term economic health of the United States. To achieve these goals the U.S. Administration participates in the single most important worldwide telecommunications regulatory and standardization body, the International Telecommunication Union—Radiocommunication Sector (ITU-R), to further its objectives with regard to all forms of wireless communication on a global basis. ITS provides ongoing technical support to the U.S. Administration in ITU-R Study Groups 3 and 5 and their Working Parties, in particular, Working Parties 3J, 3K, 3L, 3M, 5B, and 5D. In the past year, ITS has also provided support to the U.S. Administration in Working Party 6C.

STUDY GROUP 3

In the context of Study Group 3, ITS personnel serve as Chairmen of U.S. Study Group 3 and U.S. Working Party 3K, and Co-Chair of U.S. Working Party 3J. ITS personnel are also participants in the international meetings of Study Group 3 (Head of the U.S. Delegation) and Working Parties 3J, 3K, 3L, and 3M, where ITS personnel serve as Subgroup and Drafting Group Chairmen and Rapporteurs for Vocabulary. ITS personnel developed a U.S. contribution to Working Party 3J on the novel "slack string" approximation for multiple knife-edge diffraction, have contributed editorially to the Handbook on Propagation Information for Prediction of Interference and Coordination Distance, and are continuing to work closely with the United Kingdom and German Administrations on further developments of Recommendation ITU-R P.533. ITS personnel continue to support the work of Rapporteur Group "Obstacle Diffraction" of Subgroup 3J-4 (formerly Correspondence Group 3K-1).

WORKING PARTIES 5B AND 5D

In the context of Working Party 5D, an ITS engineer has provided technical support and participated as a member of the U.S. Delegation in all national and international meetings of this Working Party during the current Study Period, 2008-2012 (see Interference Issues Affecting Land-Mobile Systems, page 34). As part of this work, this ITS engineer also communicated with other U.S. national standards bodies (i.e., ATIS).

In the context of Working Party 5B, an ITS engineer provides ongoing technical support to the U.S. Administration in areas including potential reallocation of radar spectrum, communications systems interference effects on radars, dynamic frequency selection technology for spectrum sharing between communications systems and radars, the development of radar emission spectra measurement techniques and the development of more efficient radar emission spectra criteria. In addition to activities in Working Party 5B, this ITS engineer also participates in the Radar Correspondence Group and the Radar Unwanted Emissions Group.

WORKING PARTY 6C

In the context of Working Party 6C, ITS engineers prepared and presented U.S. contributions proposing alignment with video quality activities within the ITU-T. This included proposals for Preliminary Draft New Recommendations on video peak signal to noise ration (PSNR) measurement and reduced reference objective video quality measurement methods. To support this work, WP6C appointed an ITS engineer as Rapporteur for global video evaluation methodology landscape.

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The ITU is more than a century old. Meetings are held in Geneva. Top: The Geneva city flag with its heraldic symbol on the Rhone River bridge. Bottom: Members gather prior to an ITU-R meeting.

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.

Overview

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 United Nations, responsible for developing the international standards (Recommendations) that providers use to plan, interconnect, and operate public telecommunication networks and services worldwide. ITU-T Recommendations strongly impact both the evolution of U.S. telecommunication infrastructures and the competitiveness of U.S. telecommunication products in international trade.

The Institute's long-term goal in ITU-T (and related national standards work) is to motivate the standardization of user-oriented, technology-independent measures of telecommunication service quality, and to relate those measures with the technology-specific performance metrics and mechanisms providers use to provision and operate networks. This work promotes fair competition and technology innovation in the telecommunications industry, facilitates interworking among independently-operated networks and dissimilar technologies, and helps users define their telecommunication needs and select products and services that best meet them.

One way ITS promotes telecommunications standardization efforts is by accepting leadership roles in key standards development organizations (SDOs). In FY 2009, Institute staff members held several prestigious leadership roles including Chair of ITU-T Study Group (SG) 9 (Television and sound transmission and integrated broadband cable networks), Co-Chair of the ITU Video Quality Experts Group (VQEG), and Co-Chair of the Joint Rapporteur Group on Multimedia Quality Assessment (JRG-MMQA). An ITS staff member served as Vice-Chair of the Alliance for Telecommunications Industry Solutions (ATIS) Network Performance, Reliability, and Quality of Service Committee (PRQC), Chair of PRQC's QoS Task Force, and Vice-Chair of the PRQC's Security Task Force.

ITU-T Study Group 9

ITU-T Study Group 9 carries out studies on the use of telecommunication systems for broadcasting of television and sound programs and the use of cable television networks to provide interactive video services, telephone, and data services, including Internet access. Among the Recommendations standardized by ITU-T SG9 are those defining video and multimedia quality assessment and those supporting Emergency Telecommunications over broadband cable networks.

While this project provides input to ATIS, the Society of Cable Telecommunications Engineers (SCTE), the Internet Engineering Task Force (IETF), and the ITU-R, the majority of work is directed to the ITU-T Study Group 9 and VQEG. In FY 2009, Arthur Webster served as international Chair of ITU-T SG 9, which is responsible for broadband cable networks and television and sound transmission. Margaret Pinson co-chairs Question 14/9 (Objective and Subjective Methods for Evaluating Audiovisual Quality in Multimedia Services) and serves as Head of the U.S. Delegation to ITU-T SG9.

VQEG

An ITS staff member founded the Video Quality Experts Group and has co-chaired it since 1997. VQEG enables video experts from many countries to collaborate in developing and evaluating video quality metrics (VQMs). The group's reports strongly impact the standardization of VQMs in both ITU-T and ITU-R. VQEG works largely via an e-mail reflector, publicly accessible at http://www.VQEG.org. During FY 2009 the number of participants subscribed to this reflector grew to over 600. VQEG produces independent validation data, which the U.S. considers to be a key prerequisite for standardizing a VQM. Thus, VQEG acts as a cooperative technical advisory committee that facilitates standardization efforts in ITU-T SG 9, SG 12 (Performance and QoS), and ITU-R WP 6C (Broadcasting Services—Programme Production and Quality Assessment) to develop objective, computer implementable, perception-based video and multimedia quality metrics that emulate the human visual system.

Arthur Webster chairing the first meeting of ITU-T Study Group 9 in FY 2009.

ITS staff members provide key leadership and technical contributions to VQEG. Arthur Webster co-chaired VQEG and chaired the two meetings that occurred in FY 2009. Margaret Pinson co-chaired the HDTV effort, which finalized a test plan and began validation of HDTV models in response to urgent industry requests. ITS also assisted in finalizing and documenting VQEG's Reduced Reference—No Reference (RR-NR) TV test, and developing the Hybrid Perceptional Bit-Stream video test plan. Through the combined efforts of this and other ITS projects, the Institute provided key video source material that comprises most of the validation sequences used in the HDTV effort. ITS is spearheading new ITU-T work on audiovisual quality assessment through its leadership in VQEG.

In related work, ITS leads the ITU-T's Joint Rapporteur Group on Multimedia Quality Assessment (JRG-MMQA). This is a cross-cutting ITU-T standards body that unites the video quality expertise of SG 9 with the audio and network quality expertise of SG 12 in an effort to develop objective, perception-based metrics for combined audio and video signals in mobile and PC environments. The JRG-MMQA typically meets concurrently with VQEG. The JRG-MMQA provides an official mechanism for coordination of VQEG activities with ITU-T SG9 and ITU-T SG12.

FY 2009 saw the completion of VQEG's Reduced Reference—No Reference Television Project. The results of this validation test were reported to the ITU, and ITU-T Study Group 9 prepared two Draft New Recommendation based upon VQEG's test results:

- J.249 (J.redref), "Perceptual video quality measurement techniques for digital cable television in the presence of a reduced reference."
- J.340 (J.ra-psnr), "Reference algorithm for computing peak signal to noise ratio (PSNR) of a processed video sequence with compensation for constant spatial shifts, constant temporal shift, and constant luminance gain and offset."

ATIS PRQC

ATIS PRQC develops national standards and contributes to ITU-T standardization in network performance and security. The Institute's PRQC leaders organized and managed two face-to-face PRQC meetings during FY 2009. Among other outputs, the group produced the following standards in which ITS engineers served as editor or author:

- Reduced Reference Video Calibration Estimation Method.
- User-Network Interface (UNI) Media Plane Security Standard for Evolving VoIP/Multimedia Networks.

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ITS maintains the Table Mountain Field Site's buildings and resources, like this turntable, for telecommunications research (photograph by J.W. Allen).

The RSMS 4th Generation measurement vehicle at Table Mountain (photograph by J.W. Allen).

ITS Tools and Facilities

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. In turn, these capabilities 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 efficient and robust 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 the highest 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 recorders, digital audio tape machines, and CD players. These systems are augmented with several digital audio and video workstations and numerous top-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 acoustic environments are available for the subjective testing of audio and video signals. The controlled environments are specified in ITU-T Recommendation P.800 and ITU-R Recommendation BT.500, respectively. These specifications address background noise levels, wall colors, light levels, room dimensions, and other properties.

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. Four systems offer the ability to record and play uncompressed digital audio bit-streams together with synchronized uncompressed SD and HD video bit-streams that conform to ITU-R and SMPTE Recommendations (e.g., SMPTE 259M/272M, 292M). Audio and video processing is performed on high-performance workstations, supported by high-capacity RAID arrays for storage of the uncompressed audio and video streams.

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 ANSI T1.801.03-2003, ITU-T Recommendation J.144, 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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Automated Wideband Noise Measurement System

To address a renewed interest in measuring, quantifying, and modeling man-made radio noise, ITS has developed a new, automated wideband noise measurement system. The measurement system consists of an antenna, ITS custom-built preselector, vector signal analyzer (VSA), and personal computer. The cornerstone of the system is the VSA that permits wideband noise measurements in up to 36 MHz of bandwidth and permits the recording of digitized in-phase/quadrature (I/Q) samples of the entire noise signal.

The capability of this system to record actual I and Q signal data in a wide bandwidth provides many options as to how the data can be processed and further utilized. The preselector contains a fixed bandpass filter tuned to the measurement frequency, a low pass filter, and a low noise amplifier (LNA). The filters can be easily exchanged (or replaced by a tunable bandpass filter) to conduct noise measurements at different frequencies. This configuration provides for a very sensitive measurement system with a noise figure (NF) of approximately 3dB. The antenna used for this system is a quarter-wave monopole, tuned to the desired measurement frequency and mounted on a ground plane.

The personal computer is used to run software developed by ITS to control the noise measurement. This software allows the user to set the measurement frequency, bandwidth (span), number of data points, and other parameters. Once the measurement is started, it will automatically collect data at user-defined time intervals for a user-specified duration. The capability to perform and display results of noise diode calibrations, spectrum captures, and single, manual noise measurement data captures is also included in the software.

To provide a high degree of RF shielding between the measurement equipment and the antenna, as well as AC power, temperature control, and shelter, the noise measurement system is currently housed in the RSMS-4G measurement vehicle.

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Boulder Labs Frequency Manager

ITS provides assistance to government and private industry users for frequency usage at the Table Mountain Radio Quiet Zone and stations in the area exhibiting the following conditions of effective radiated power (ERP) and radial distance:

- All stations within 2.4 kilometers.
- Stations with 50 W or more ERP within 4.8 kilometers.
- Stations with 1 kW or more ERP within 16 kilometers.
- Stations with 25 kW or more ERP within 80 kilometers.

Requests for coordination at the Department of Commerce Boulder Laboratories are also managed. The coordination process may require analyses to be performed utilizing various propagation prediction models in order to resolve potential electromagnetic interference problems.

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Digital Sampling Channel Probe

The digital sampling channel probe (DSCP), designed and patented by ITS, is used to characterize wideband propagation characteristics of the radio channel. Consisting of a transmitter, receiver, and data acquisition system, the DSCP is used to make impulse response measurements. The DSCP can be configured to transmit orthogonal pseudo noise codes at the same RF frequency for MIMO studies or variable rate codes at multiple RF frequencies.

The DSCP receiver down-converts and digitizes the pseudo-noise signal at an intermediate frequency (IF) and then post processes the data to calculate the channel impulse response. The system can collect data on 1-8 channels every 600-800 µs, allowing characterization of the Doppler spectrum and time variability of the mobile channel for systems up to 5.8 GHz.

Historically, the DSCP was employed for channel characterization of cellular and personal communications services. ITS has expanded the probe to eight channels capable of mobile phased array or MIMO measurements. Also available is a high-frequency probe, particularly suited for high resolution requirements such as wireless local area network (LAN) applications up to 30 GHz. The probe's measurement range has been extended down to the UHF TV bands where it has been used for short-range, mobile-to-mobile channel characterization. In this mode of operation a variable bit rate code generator is used to allow simultaneous recordings at different bandwidths and frequencies. For more information, 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 provides access to the ITS local area network (LAN) while the 802.11 link connects this field site to ITS' Wireless Networks Research Center.

The site can provide six independent duplex fiber channels to the ITS lab. This allows research to be conducted over an isolated one-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 sites. These links provide 802.11b services and are also used for network performance testing. The site's unique 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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ITS Internet Services

ITS provides public Internet access to NTIA/ITS publications, program information, meeting information, and on-line 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 standards committees. Highlights of ITS Internet Services include:

- Information about ITS programs and projects. Available at http://www.its.bldrdoc.gov/programs/.
- An ITS organization chart and listing of ITS staff with contact information. Available at http://www.its.bldrdoc.gov/organization.php.
- Recent ITS publications including NTIA Reports, special publications, and journal articles. Available at http://www.its.bldrdoc.gov/pub/pubs.php.
- 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/.
- Information about and access to internet services of Telecommunications Analysis Services. Available at http://tas.its.bldrdoc.gov/.
- Video Quality Metric software. Available at http://www.its.bldrdoc.gov/n3/video/vqmsoftware.htm.
- Information about ITS-sponsored events such as ISART and ITS-led Study Groups. Available at http://www.its.bldrdoc.gov/meetings/.
- The ITS brochure. Available at http://www.its.bldrdoc.gov/ITS_brochure/ITS_brochure.pdf.

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Mobile Radio Propagation Measurement Facilities

ITS maintains and continually develops a pair of measurement vehicles comprising a transmitter-receiver system that characterizes the properties of radio channels over a wide frequency range, from VHF to 30 GHz. The transmitter vehicle has an on-board generator, a pair of telescoping masts, and a set of radio modulators and transmitters. The receiver van is equipped with on-board power, a telescoping mast, azimuth and elevation controllers, and global positioning system (GPS) devices with a dead-reckoning backup.

A suite of measurement equipment, much of it designed and built by ITS engineers, is used in the vehicle. These include wideband systems for measuring radio channel impulse responses; impulse response measurement capability at 30 GHz with 2-ns resolution, which is enhanced with a digital wideband recording system. To support mobile-to-mobile short-range propagation model development, an 8-channel receiver and an 8-channel, 14-bit data acquisition system have been developed. Multi-channel synchronous acquisition can be used for antenna array measurements and multi-frequency broadband measurements.

Mobile measurement capability allows space division multiple access (SDMA) algorithms to be implemented using data collected in a wide variety of environments (e.g., urban, rural, and suburban). This data can in turn be used to model and simulate the performance of radio systems in such environments. A suite of analysis software is continuously developed and maintained for calculating mobile propagation metrics from impulse response data. Typical metrics are power delay profiles, delay spread, received power versus bandwidth, Doppler spectrum, and coherence bandwidth.

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Public Safety Audio & Video Laboratories

One of the most challenging aspects of public safety communication is the harsh noise environment in which public safety practitioners must effectively establish and conduct voice communications. The Public Safety Audio Laboratory (PSAL) and Public Safety Video Laboratory (PSVL) are facilities for investigating the voice and video quality of public safety communication systems in harsh environments.

The PSAL consists of digital systems for mixing, storage, and distribution of audio; sound attenuated chambers for effective isolation; and International Telecommunication Union (ITU)-compliant head and torso simulators (HATS) for acoustic coupling to radio interfaces. The PSVL consists of cameras, video capture systems, video coding and decoding systems, network simulators, video editing stations, and props.

The PSAL is built on a foundation of digital audio mixing and distribution. All audio mixing, distribution, storage, and filtering are conducted in the digital realm with 48 kHz-sampled audio. This provides a high-quality, distortion-free distribution system that is not impacted by other equipment in the laboratory. The digital capabilities include: digital mixing, 24-track digital recording, 8-channel digital input and output to Windows-based computers, digital audio tape (DAT), and 1/3 octave digital filters. Usage of analog audio signals is kept to a minimum by 1) digitizing analog inputs at the input and keeping them digital throughout any processing, and 2) only performing digital-to-analog conversion on signals that are to be converted to acoustic signals.

A head and torso simulator (HATS) simulating voice distortion through SCBA field equipment.

The more specialized equipment in the PSAL includes the two HATS systems. The HATS systems are defined by the ITU in Recommendations P.58 (Head and torso simulator for telephonometry), P.57 (Artificial ears), and P.51 (Artificial mouth). These recommendations specify the physical characteristics and acoustical/electrical interface characteristics that enable a consistent simulation of the speaking and hearing frequency responses of the “average” human. The HATS enable consistent acoustic input to communications equipment under test and provide a “willing subject” that will not be subject to hearing loss when exposed to harsh noise environments for extended periods.

The PSAL system provides a reproducible acoustic path that enables emulation of the harsh noise environments encountered by public safety practitioners. The recorded output from the system can be used in a number of ways. For example, the recordings might be analyzed by an objective measurement technique such as that defined in ITU Recommendation P.862 (Perceptual evaluation of speech quality (PESQ): an objective method for end-to-end speech quality assessment for narrow-band telephone networks and speech codecs). Alternatively, the recordings might be incorporated into a subjective test experiment where listeners will rate the quality of the audio.

The primary role of the PSVL is to support the PSVQ project. In accomplishing this mission, scenes that contain selected vital elements of public safety responder uses are created and filmed on high-definition cameras. These scenes include simulations of surveillance cameras (indoor and outdoor), in-car police cameras, and search and rescue robot cameras, among others. The video is then captured and edited on the PSVL workstations. Selected scenes are processed through controlled versions of the communication systems that might be typical of what a jurisdiction may consider purchasing. The communication systems processing includes compression schemes and simulated wired and wireless networks.

To determine if a system is adequate for use in specified applications, first responders view the video and attempt to perform certain tasks such as identifying an object or reading a license plate. The results of these tests provide data for developing recommendations. Together, the PSAL and PSVL provide valuable insight into the requirements for public safety audio and video communications.

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Public Safety RF Laboratory

The Public Safety Communications Research (PSCR) RF Laboratory supports sponsor efforts to test Land Mobile Radio (LMR) systems and components in accordance with Telecommunications Industry Association (TIA) Project 25 (P25) testing standards for LMR (the TIA-102 suite of standards). The PSCR Lab staff contributes to the development and maturation of all three facets of the P25 testing standards: performance, conformance, and interoperability. The PSCR Lab implements these test standards in their laboratory activities, in support of internal research, outside agency (OA) interagency agreements (IAAs), and cooperative research and development agreements (CRADAs) with non-Federal government entities.

In 2007, the PSCR Lab completed installation of an RF screen room and developed automated test software to assess the RF performance characteristics of P25 equipment. In 2008, PSCR Lab staff installed a functional working two-site, three-channel VHF trunking system and a single-site, four-channel UHF trunking system, using commercial P25 equipment. These trunking systems are facilitating the PSCR Lab mission to contribute to the development of the Inter-RF Subsystem Interface (ISSI) as defined by TIA. In 2009 the lab developed the test tools to analyze the P25 voice, data and control channels in support of conformance testing. This effort is still ongoing.

Another ongoing external program of great interest to the PSCR Lab is the Department of Homeland Security (DHS) P25 Compliance Assessment Program (P25 CAP), a voluntary program that allows P25 equipment suppliers to formally demonstrate their products' compliance with a select group of requirements within the TIA-102 suite of P25 standards. The purpose of the program is to provide emergency response agencies with evidence that the communications equipment they are purchasing meets P25 standards for performance, conformance, and interoperability, and to ensure that testing entities are implementing P25 test procedures correctly. The PSCR Lab is now undertaking the task of implementing the practices developed by the DHS P25CAP Governing Board, in order to allow the PSCR Lab to be as capable of performing the performance, conformance, and interoperability tests that P25CAP-recognized laboratories perform.

While the primary use for the PSCR Lab is the testing of P25 LMR systems and components, the underlying infrastructure and analysis facilities of the PSCR lab can support a much broader range of tests and radio equipment. This capability is available on a first-come, first-served basis to both NTIA and other agencies.

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Pulsed Radar Target Generator

The Pulsed 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. Some radar models transmit modulated pulses. The generator can produce modulated pulses such as chirped and phase coded modulations (including the popular Barker code set). 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 has used 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 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, which is now in its 4th generation. The vehicle has a highly shielded enclosure (60 dB) with three equipment racks, three 10-meter masts, a 20-kW 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 the immediate needs. A major objective in the development of the 4th generation software has been to provide a tool that can easily accommodate new equipment and different hardware configurations, and 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 provides 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 systems can result 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 system's effects within its actual or proposed operating environment to determine its impact on other radio spectrum users. Another problem is to adequately produce controlled interfering signals with known characteristics in environments where suspected interferers may be unavailable for tests and measurements. This includes situations such as laboratory investigations of possible interference from ship or aircraft-mounted radars or terrestrial or space-based communications systems. In these situations, a system is needed that simulates the spectral emissions of other devices with a wide range of latitude and fidelity.

To meet these needs, ITS engineers have developed two 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 has used 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 that ITS uses for generating interference is to utilize high-speed digitizers, called vector signal analyzers (VSAs), to record interference waveforms in bandwidths up to 36 MHz, and to then either 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 the requisite mathematical information to create particular waveform modulations, such a quadrature phase shift keyed (QPSK) signals.

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 using VSGs to generate interference 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 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 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** — Table Mountain, a flat-topped butte with uniform 2% slope, 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.

As an example of the size of the Table Mountain Field Site, this photograph was taken at one of the available facilities. The small white speck on the low ridge is another of the facilities (photograph by J.W. Allen).

- **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 digital signal transmission, environmental and man-made noise, verification of antenna propagation models, and the development of measurement methods needed to assess efficient spectrum occupancy and usage. Partnerships and cooperative research activities with other agencies are encouraged at the site. Learn more online at: http://www.its.bldrdoc.gov/table_mountain/.

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Telecommunications Analysis Services

The Telecommunications Analysis (TA) Services program provides the latest ITS-developed engineering models and research data to industry and other Government Agencies via the web at: http://tas.its.bldrdoc.gov/. 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; the U.S. Census data for 2000, 1997 update, and 1990; FCC databases; and 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 have been developed. 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.

Many facilities at Table Mountain, like this research station, are being upgraded as a part of a modernization project at the site (photograph by J.W. Allen).

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 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).

Learn more about Telecommunications Analysis Services online at: http://tas.its.bldrdoc.gov/.

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Wireless Networks Research Center

The Wireless Networks Research Center (WNRC) provides a common laboratory area for research in 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-RAN. ITS also has the capability to simulate PCS interference using a series of ITS implemented interference models.

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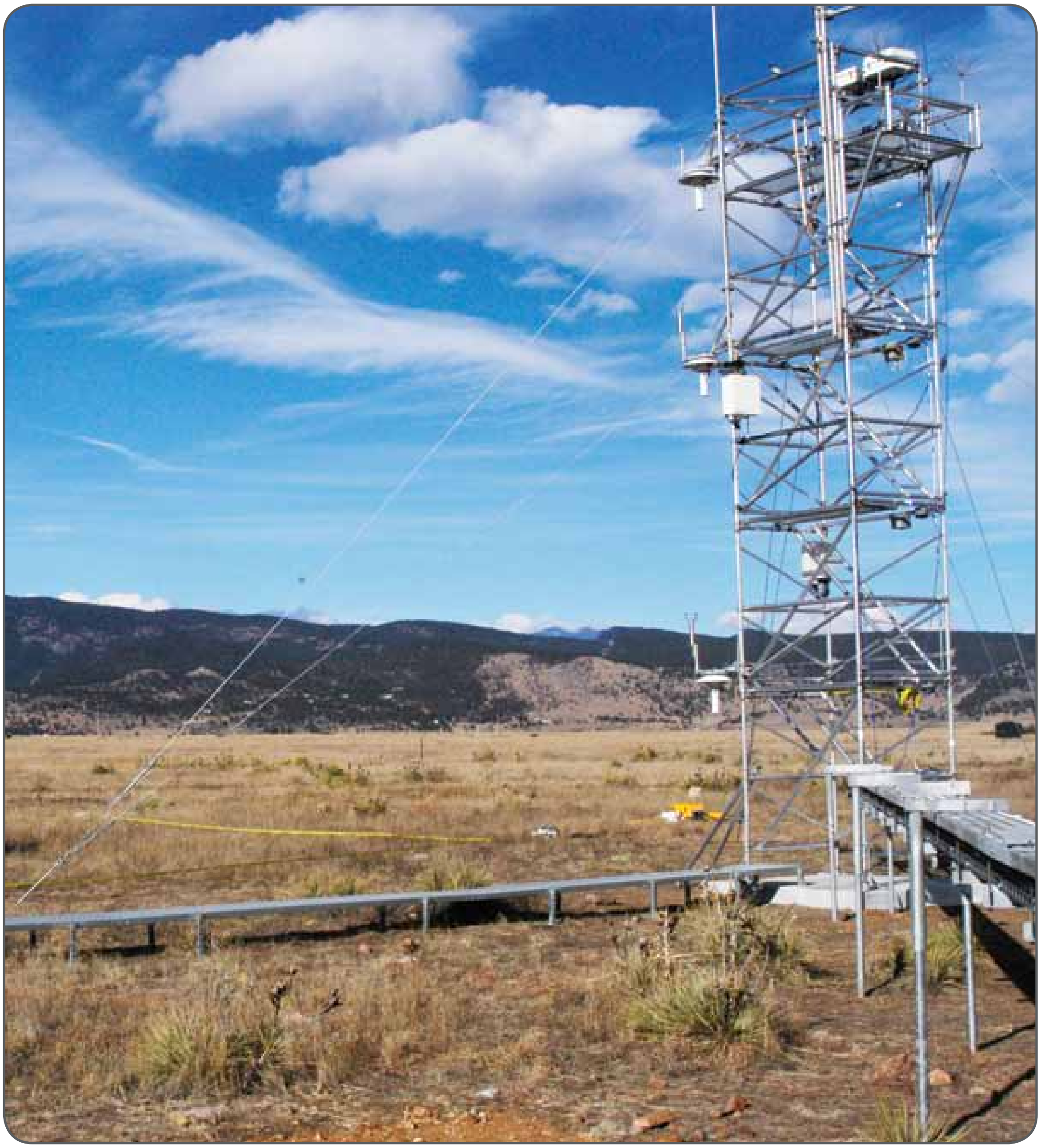

The National Ecological Observatory Network (NEON) facility at the Table Mountain Field Site (photograph by J.W. Allen).

ITS Projects in FY 2009

NTIA S&E Projects

Audio Quality Research

Develop and evaluate new techniques for encoding, decoding, and analyzing speech signals. Provide algorithms, software, and technical expertise to other ITS programs. Provide technical presentations and laboratory demonstrations as requested.

Project Leader: Stephen D. Voran (303) 497-3839
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Broadband Wireless Research

Deploy state-of-the-art measurement systems for collecting broadband radio-wave propagation data, to promote spectrum extension, aid in the development of 3G and 4G cellular systems, and evaluate proposed short range unlicensed device interference.

Project Leader: Dr. Robert Johnk (303) 497-3737
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Broadband Wireless Standards

Provide leadership and technical support to committees (e.g., ITU-R SG 3/WP 3K, 3J, 3M, and 3L, TIA TR-8) developing broadband wireless communications standards that affect Federal agencies' use of the services. Building on previous ITS work, develop model comparisons for each propagation model.

Project Leader: Paul M. McKenna (303) 497-3474
pmckenna@its.bldrdoc.gov

Effects of the Channel on Radio Systems

Identify, model, and characterize a small number of radio systems and use these to predict the effects of the channel on others. Use the results to predict how interference introduced by new spectrum engineering methods impacts legacy systems.

Project Leader: Robert J. Achatz (303) 497-3498
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Multimedia Quality Research

Develop a subjective methodology to measure audio-visual quality. Create a single, cohesive audiovisual model, that objectively predicts multimedia quality through a combination of audio quality, video quality, and audiovisual synchronization information.

Project Leader: Arthur A. Webster (303) 497-3567
awebster@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), and resource management standards.

Project Leader: Arthur A. Webster (303) 497-3567
awebster@its.bldrdoc.gov

Networking Technology

Research, develop, and demonstrate state-of-the-art methods and tools related to the measurement of wireless data networks, such as wireless local area networks (WLANs). Develop network-based measurement methods for Voice over IP (VoIP) quality.

Project Leader: Dr. Robert Stafford (303) 497-7835
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Noise and Spectrum Occupancy Measurement Research

Characterize and track over time the levels of radio channel noise in various frequency bands and environments. Identify areas of greatest need, design and implement systems to perform measurements in those areas, and report on the results. Conduct spectrum usage surveys.

Project Leader: Jeffery A. Wepman (303) 497-3165
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RSMS Enhancements

Support RSMS operations through the development and maintenance of software, hardware, systems, and equipment.

Project Leader: John E. Carroll (303) 497-3367
jcarroll@its.bldrdoc.gov

RSMS 4th Generation Development

Provide new and innovative measurement hardware and software tools for current and future RSMS capabilities. Project future needs and develop long-term strategies for building the necessary tools.

Project Leader: J. Randy Hoffman (303) 497-3582
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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: John E. Carroll (303) 497-3367
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Table Mountain Modernization

Maintain and upgrade the Table Mountain Field Site infrastructure, ensure a safe working environment there, and provide logistical support for research activities at the field site.

Project Leader: J. Wayde Allen (303) 497-5871
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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 in order to expand ITS' knowledge base, identify emerging technologies, and develop new measurement methods.

Project Leader: J. Wayde Allen (303) 497-5871
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3rd Generation Wireless Interference Modeling and Characterization

Present technical contributions on PCS interference effects to ATIS Technical Subcommittee WTSC-RAN. Contribute to related fora (e.g., ITU-R Working Parties 5D, 3K, and 3M) as appropriate. Develop a technology-independent, multi-channel PCS interference model for use in the evaluation of CMRS and other potentially affected (e.g., public safety) systems.

Project Leader: Timothy J. Riley (303) 497-5735
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Video Quality Research

Develop technology for assessing the performance of digital video transmission systems. Improve measurement technology for multimedia definition (MD) and high definition (HD) video systems. Facilitate the development of international video quality measurement standards by participating in both the Independent Lab Group (ILG) of the Video Quality Experts' Group (VQEG) and as a proponent for new RR measurement technology for both Standard Definition (SD) and HD TV systems.

Project Leader: Stephen Wolf (303) 497-3771
swolf@its.bldrdoc.gov

NTIA/OSM Projects

Characterization of Low Noise Amplifiers

Characterize the response of low noise amplifiers (LNA) from several manufacturers to single and multiple interfering signals. Attempt to gain insight into the effects of manufacturer design choices on the performance of LNAs.

Project Leader: Yeh Lo (303) 497-3393
ylo@its.bldrdoc.gov

Development of Methodology for Statistical Combinations of Noise and Interference

Develop guidance/guidelines as to when an interfering signal that is combined with a noise signal can be considered "noise-like." Document the guidance and guidelines in a technical memorandum that will be incorporated into the Best Practices Handbook.

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

Effects of Receiver Signal Processing on Interference Rejection

Determine the feasibility of using a commercially available computer capability to simulate the signal processing for a range of different error correction schemes. Implement this capability to evaluate the performance of a radio system subjected to signals from other radio links.

Project Leader: Robert J. Achatz (303) 497-3498
rachatz@its.bldrdoc.gov

Minimum Detectable Signal in GPS Bands

Perform technical measurements and analyses to investigate the problem of determining minimum detectable signal levels in GPS bands, at and near 1575 MHz. Report results to OSM.

Project Leader: Yeh Lo (303) 497-3393
ylo@its.bldrdoc.gov

Spectrum Sharing Innovation Test-Bed Pilot Program

Develop and build measurement systems for each of the measurements. Perform measurements that examine the feasibility of increased frequency sharing.

Project Leader: Eric D. Nelson (303) 497-7410
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Radar Support Tasking

Support USWP8B, USJRG, and the U.S. Administration's positions in ITU-R WP8B and JRG 1A-1C-8B by providing position papers, technical reports, and attendance in these forums. Also support the Radar Correspondence Group (RCG) and the JRG 1A-1C-8B and RCG websites.

Project Leader: Frank H. Sanders (303) 497-7600
fsanders@its.bldrdoc.gov

Short-Range Mobile-to-Mobile Propagation Prediction Model

As part of a multi-year effort to address the need for an under-1 km propagation prediction model, continue looking at this specific scenario and its unique environmental influences. Continue model development and a field measurement campaign to verify

and validate those models. Bring the results of the project to the ITU-R and IEEE, as appropriate.
Project Leader: Paul M. McKenna (303) 497-3474
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Spectrum Efficiency of the Radiodetermination Service

With OSM, develop a report on the basic parameters and trade-offs to consider in an analysis of spectrum efficiency of the radiodetermination service, and provide example calculations of spectrum efficiency for some simple radars. Develop an analytical approach to radar spectrum efficiency in general.
Project Leader: Frank H. Sanders (303) 497-7600
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Other Agency Projects

Department of Commerce / NIST / Office of Law Enforcement Standards

Public Safety Telecommunications Interoperability

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. Provide technical assessments and evaluations of commercial products and services that may provide interim solutions for various interoperability scenarios.
Project Leader: Jeffrey R. Bratcher (303) 497-4610
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Analysis, Demonstration, T&E

Project Leader: DJ Atkinson (303) 497-5281
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Assessment of Integration Strategies

Project Leader: Kameron A. Behnam (303) 497-3830
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Development of Requirements, AF Interoperability Standards

Project Leader: Andrew P. Thiessen (303) 497-4427
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Lab Equipment and Support

Project Leader: Jeffrey R. Bratcher (303) 497-4610
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Video Clip Preparation

Project Leader: Margaret H. Pinson (303) 497-3579
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Fading Characteristics Verification

A measurement effort to characterize radio channel characteristics relevant to public safety.
Project Leader: Christopher Redding (303) 497-3104
credding@its.bldrdoc.gov

Public Safety Video Quality Testing

Develop and conduct video quality tests to assist public safety agencies with telecommunications systems and equipment selections. Analyze data and write a report on the results.
Project Leader: Dr. Carolyn Ford (303) 497-3728
cford@its.bldrdoc.gov

Department of Commerce / NOAA / NOAA Weather Radio Program Office

NOAA Weather Radio Receiver Tests

Compile the characteristics and responses of NWR receivers to various simulated NWR transmissions.
Project Leader: Raian F. Kaiser (303) 497-5491
rkaiser@its.bldrdoc.gov

Department of Defense

Enhancements to Communication System Planning Tool (CSPT) for DOD

Enhance the ITS CSPT model through improvements in the incorporated models and addition of models, as well as user support.
Project Leader: Julie Kub (303) 497-4607
jkub@its.bldrdoc.gov

PMW (Propagation Modeling Website) for DOD

Create version 1.0 of the PMW to allow users to run single and batch TIREM and ITM propagation models, save them to a database, and display on a GIS (Geographic Information System) web site.
Project Leader: Julie Kub (303) 497-4607
jkub@its.bldrdoc.gov

Department of Defense / U.S. Air Force

Development of RNSS Sampled Waveforms

Measure the emission spectra and capture I/Q waveforms for four RNSS SV transmission modulations in the 1215-1400 MHz frequency band.
Project Leader: Brent L. Bedford (303) 497-5288
bbedford@its.bldrdoc.gov

Department of Defense / U.S. Army

RSEC Measurements on a TPQ-48 Radar

Measure the emission spectrum and related emission characteristics of the Army TPQ-48 man-portable radar.

Project Leader: Frank H. Sanders (303) 497-7600
fsanders@its.bldrdoc.gov

Department of Defense / Naval Research Laboratory

JCREW S&T Modeling and Characterization Program

Develop a radio-wave propagation model for NRL's Joint Counter Radio Controlled Electronic Warfare Science & Technology (JCREW S&T) Modeling and Characterization Program. Project developed, verified, and validated a radio-wave propagation model for short to medium distances ranging from 2 meters to 2 kilometers, and very low antenna heights. These efforts involved both analysis, measurements, and model development

Project Leader: Nicholas DeMinco (303)497-3660
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Department of Homeland Security / Federal Partnership for Interoperable Communications

DHS/FPIC Technical Engineering Support

Provide engineering support to Federal Partnership for Interoperable Communications (FPIC) for public safety radio standards development and testing in the ITS test facility. Assist in the development of P25 standards in accordance with the APCO P25 Interface Committee (APIC) and TIA procedures. Identify conditions advanced by P25 vendors or interested parties that require further engineering analysis by an independent entity.

Project Leader: DJ Atkinson (303) 497-5281
datkinson@its.bldrdoc.gov

Department of Homeland Security / National Communications System

ETS Standards Development

Facilitate the standardization of NS/EP specifications, protocols, and mechanisms. Develop and/or verify emergency telecommunications service (ETS) mechanisms. Assist NCS in support of PDD-63 and associated CIP initiatives.

Project Leader: Arthur A. Webster (303) 497-3567
awebster@its.bldrdoc.gov

Department of Homeland Security / Office of the CIO

Standardization of Measurement Methods for Investigative Devices

Provide engineering and technical support to the OCIO Wireless Management Office for development of standardized measurement methods of investigative devices. Conduct measurements on new and/or proposed investigative devices defined by DHS.

Project Leader: DJ Atkinson (303) 497-5281
datkinson@its.bldrdoc.gov

Department of Interior / National Park Service

Acadia National Park Communications Alternatives Study

Provide coverage plots of the present communications capabilities at Acadia National Park. Perform single, double, and triple alternative base station location evaluations. Provide analysis tools to assess the viability of each alternative.

Project Leader: Christopher Behm (303) 497-3640
behm@its.bldrdoc.gov

Department of Transportation / Federal Aviation Administration

Wind Turbine Radar Interference Assessment

Provide an independent and objective assessment of the effects that wind turbines may have on air traffic control radar operations and suggest methods for mitigating such effects if found to be harmful.

Project Leader: Frank H. Sanders (303) 497-7600
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Department of Transportation / 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 Committee (WCC).

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

National Aeronautics and Space Administration

EM Characterization at a NASA Space Power Facility

Provide a direct-pulse measurement system for the NASA Space Power Facility. Perform measurements of insertion loss and chamber energy decay times.

Project Leader: Dr. Robert Johnk (303) 497-3737
bjohnk@its.bldrdoc.gov

National Archives and Records Administration

NARA E-Government Study

Demonstrate and evaluate the "Information Portal" concept to allow NARA to offer a system that will improve knowledge sharing across the organization and complement their physical records storage practice with an electronic version of the same.

Project Leader: Alan W. Vincent (303) 497-3500
avincent@its.bldrdoc.gov

Various Federal & Non-Federal Agencies

Telecommunications Analysis Services

Develop and maintain TA Services analysis tools (propagation models) and their corresponding interfaces to users and databases, including maintenance and development of GUIs and various databases.

Project Leader: Julie Kub (303) 497-4607
jkub@its.bldrdoc.gov

Cooperative Research and Development Agreements (CRADAs)

Areté Associates

Coded Aperture Ladar for Long Range Applications

Support Areté Associates in testing and demonstrating laser radar technologies at the Table Mountain Field Site.

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

First RF Corporation

Installed Performance of Antennas

Support First RF in testing antenna system performance on a number of vehicles including UAVs, using the turntable facility at the Table Mountain Field Site.

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

Lockheed Martin Coherent Technologies

Laser Testing at Table Mountain

Support LMCT's field-testing and characterization of components, subsystems, and systems for eyesafe coherent laser radar at Table Mountain Field Site.

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

RF Metrics

A Study of the Use of a Novel Antenna Pattern Collection Technique for Radar Emissions

Support RF Metrics' attempts to measure a radar system using the test procedures outlined in the ITU-R M-1177 standard and measure the antenna pattern using the technique described in NTIA Report TR-06-436.

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

State of Wyoming

Public Safety Radio Testing Program

Test and evaluate P25 subscriber units from a variety of different vendors, in order to provide the State of Wyoming with technical results to aid in determining the viability of using multi-vendor P25 subscriber units in the WyoLink Statewide system.

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

University of Colorado

Ad hoc UAV Ground Network Test-Bed (AUGNet)

Support CU's experiments with communication networks between low-cost small unmanned aerial vehicles similar to model radio-controlled (RC) airplanes, and ground-based radios.

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

ITS Publications and Presentations in FY 2009

NTIA Publications

A. Catellier and S. D. Voran, "Relationships between intelligibility, speaker identification, and the detection of dramatized urgency," NTIA Technical Report TR-09-459, Nov. 2008.

> The systems used for public safety speech communications must be intelligible. It is also desirable that they transmit secondary information, such as the attributes of a speaker's voice. This secondary information can allow a user to identify the speaker and his or her emotional state. Testing speech communications systems for the delivery of intelligible speech is common. Testing for human perception of the delivery of this secondary information is less common, though some prior work has been done. Building on this prior work, we describe a set of controlled laboratory listening experiments. These experiments characterize the relationships between speech intelligibility, speaker identification, and the detection of dramatized urgency in a speaker's voice across a range of simulated speech processing conditions. The experiment results indicate that for the speech processing conditions considered here, detection of dramatized urgency is the most robust property, speaker identification is less robust, and speech intelligibility is the least robust.

R. Dalke, "Statistical considerations for noise and interference measurements," NTIA Technical Report TR-09-458, Nov. 2008.

> The study of noise and interference in the radio environment is essential to the development of efficacious communications systems. Many of the characteristics of radio noise and interference of interest to radio system designers can be expressed in terms of first- and second-order statistics. These statistics are necessarily calculated using measured data. In this report, we discuss uncertainties that arise when measured data sets are used to calculate statistics of radio noise and interference.

M.H. Pinson and S. Wolf, "Techniques for evaluating objective video quality models using overlapping subjective data sets," NTIA Technical Report TR-09-457, Nov. 2008.

> This report presents techniques for evaluating objective video quality models using overlapping subjective data sets. The techniques are demonstrated using data from the Video Quality Experts Group (VQEG) Multi-Media (MM) Phase I experiments. These results also provide a supplemental analysis of the performance achieved by the objective models that were submitted to the MM Phase I experiments. The analysis presented herein uses the subjective scores from the common set of video clips to map all the subjective scores from the 13 or 14 experiments (at a given image resolution) onto a single subjective scale. This mapping greatly increases the available data and thus allows for more powerful analysis techniques to be performed. Resolving power values are presented for each model and image resolution. On a per-clip level, models' responses to stimuli are analyzed with respect to all stimuli, each coding algorithm, coding-only impairments, and transmission error impairments. The models' responses to stimuli are also analyzed on per-system and per-scene levels. Results indicate the amount of improvement possible when averaging over multiple scenes or systems.

S. Wolf, "A No Reference (NR) and Reduced Reference (RR) metric for detecting dropped video frames," NTIA Technical Memorandum TM-09-456, Oct. 2008.

> Digital video transmission systems consisting of a video encoder, a digital transmission method (e.g., Internet Protocol – IP), and a video decoder can produce pauses in the video presentation that result from dropped or repeated video frames. For example, a common response of a video decoder to dropped IP packets is to momentarily freeze the video by repeating the last good video frame. This document presents a No Reference (NR) metric and

a Reduced Reference (RR) metric for detecting these dropped video frames. These metrics may have application for in-service video quality monitoring.

Outside Publications

Articles in Conference Proceedings

L. Barclay, C. Behm, and S. Carroll, "Digitally-modulated HF communications reliability: Modifications to ITU-R Rec. P.533 propagation model and the associated computer program REC533," in *Proc. 11th International Conference on Ionospheric Radio Systems and Technologies IRST 2009*, Edinburgh, Scotland, Apr. 28-30, 2009.

This paper details the development of a new digital modulation reliability algorithm. The paper examines the algorithm's new capabilities as they appear in the newest version of ITU-R Recommendation P.533 ("Method for the prediction of the performance of HF circuits") as implemented in the computer program REC533. REC533 includes elements of several other Recommendations but is predominantly based on ITU-R P.533. REC533, which uses six F2 layer and three E layer propagation paths to predict digital modulation reliability, is discussed in detail. In addition, the four new input parameters that relate to digital modulation reliability (amplitude ratio, time window, frequency window, and required signal-to-interference ratio) are examined. Finally, the paper discusses the scope and significance of the new algorithm's reliability calculations.

C.G. Ford, M.A. McFarland, and I.W. Stange, "Subjective video quality assessment methods for recognition tasks," in *Proc. SPIE Electronic Imaging Conference 2009*, San Jose, Calif., Jan. 19-22, 2009.

To develop accurate objective measurements (models) for video quality assessment, subjective data is traditionally collected via human subject testing. The ITU has a series of Recommendations that address methodology for performing subjective tests in a rigorous manner. These methods are targeted at the entertainment application of video. However, video is often used for many applications outside of the entertainment sector, and generally this class of video is used to perform a specific task. Examples of these applications include security, public safety, remote command and control, and sign language. For these applications, video is used to recognize objects, people or events. The existing methods, developed to assess a person's perceptual opinion of quality, are not appropriate for task-based video. The Institute for Telecommunication Sciences (ITS), under a program from the Department of Homeland Security and the National Institute for Standards and Technology's Office of Law Enforcement (NIST/OLES), has developed a subjective test method to determine a person's ability to perform recognition tasks using video, thereby rating the quality according to the usefulness of the video quality within its application. This new method is presented, along with a discussion of two examples of subjective tests using this method.

R.T. Johnk, J.D. Ewan, P. McKenna, R.L. Carey, N. DeMinco, and K.A. Shalkhauser, "Time-domain pulsed measurements of the NASA space power facility," in *Proc. IEEE EMC Symposium*, Austin, Texas, Aug. 17-21, 2009.

This paper describes a recent measurement effort conducted by the Institute for Telecommunication Sciences at a chamber located at the NASA Space Power Facility (SPF) in Sandusky, Ohio. The paper describes the chamber and the measurement system, and provides some selected time- and frequency-domain results. A detailed description of the measurement procedures and post-processing is provided. The results obtained indicate that the SPF chamber exhibits robust reverberant behavior. The flexibility and efficiency of time-domain measurements is also demonstrated.

R.T. Johnk, P. Papazian, P. McKenna, N. DeMinco, G. Sanders, and H. Ottke, "A mobile propagation measurement system," in *Proc. IEEE EMC Symposium*, Austin, Texas, Aug. 17-21, 2009.

This paper describes a mobile-to-mobile propagation measurement system that is currently being developed at the Institute for Telecommunication Sciences under the sponsorship of the Office of Spectrum Measurement. This system uses a fixed transmitter truck and a moving receiver van to characterize radio-frequency channels of selected urban and rural environments. The transmitting antennas are set in a fixed location at a nominal height of 1.5 m, and the receiving antennas are located on the roof of a van at a height of 2.2 m. Measurements are typically carried out over the range of 10 m to 3 km. The transmitter and receiver architectures are described, and selected time-and frequency-domain measurement results are presented. The results obtained so far are very promising and demonstrate the versatility and effectiveness of this measurement system.

J. Perez, M. Beltran, M. Morant, R. Llorente, A. Rahim Biswas, R. Piesiewicz, M. Cotton, D. Führer, B. Selva, I. Vucaille, and S. Zeisberg, "Experimental analysis of 3.5 GHz WiMAX 802.16e interference in WiMedia-defined UWB radio transmissions," in *Proc. 69th IEEE Vehicular Technology Conference*, Barcelona, Spain, Apr. 26-29, 2009.

While useful speech communication systems must be intelligible, most systems aim to transmit secondary information, such as attributes of a speaker's voice, as well. This secondary information can allow a listener to identify the speaker and his emotional state. Testing speech communications systems for the delivery of intelligible speech is common, but testing for human perception of the delivery of this secondary information is less common, though some prior work has been done. Building on this prior work, we describe the design, implementation, analysis and results of a new listening experiment that characterizes the listener identification of six different speakers using six different low-rate digital speech communication systems. We display these experimental results along with results from our prior work to quantify listener detection of dramatized speaker urgency and word intelligibility in sentence context for the same six speech communication systems. We conclude that the speaker identification task used in this experiment is about three times more robust to communication system degradations than word intelligibility in sentence context.

S. Voran and A. Catellier, "Gradient ascent paired-comparison subjective quality testing," in *Proc. of the IEEE First International Workshop on Quality of Multimedia Experience (QoMEX)*, San Diego, Calif., Jul. 29-31, 2009.

Subjective testing is the most direct means of assessing audio, video, and multimedia quality as experienced by users. And an important goal is to maximize the information gathered while minimizing the number of trials. We propose gradient ascent subjective testing (GAST) as an efficient way to locate optimizing sets of coding or transmission parameter values. GAST combines gradient ascent optimization techniques with paired-comparison subjective test trials to efficiently locate parameter values that maximize perceived quality. We used GAST to search a two-dimensional parameter space for the known region of maximal audio quality as proof-of-concept. That point was accurately located and we estimate that conventional testing would have required at least 27 times as many trials to generate the same results.

S. Wolf, "A no reference (NR) and reduced reference (RR) metric for detecting dropped video frames," in *Proc. of the 4th International Workshop on Video Processing and Quality Metrics for Consumer Electronics*, Scottsdale, Ariz., Jan. 15-16, 2009.

Digital video transmission systems consisting of a video encoder, a digital transmission method (e.g., Internet Protocol — IP), and a video decoder can produce pauses in the video presentation that result from dropped or repeated video frames. For example, a common response of a video decoder to dropped IP packets is to momentarily freeze the video by repeating the last good video frame. This paper presents a No Reference (NR) metric and a Reduced Reference (RR) metric for detecting these dropped video frames. These metrics may have application for in-service video quality monitoring.

Journal Articles

K. Brunnström, D. Hands, F. Speranza, and A. Webster, "VQEG validation and ITU standardization of objective perceptual video quality metrics," *IEEE Signal Processing Magazine*, pp. 96-101, May 2009.

There has been an increasing desire from industry to have access to accurate and reliable objective video and multimedia quality metrics.

This has become more pressing with the advent of new video applications and services such as mobile broadcasting, internet video, and internet protocol television (IPTV). Industry-class objective perceptual quality measurement models have a wide range of uses, including pre-launch equipment testing (e.g., codec evaluation), transmission planning and network dimensioning tasks, head-end quality assurance, in-service network monitoring, and client-based quality measurement. It is common for vendors to develop operational-grade objective models that are supported by the vendors' own performance data. Naturally, industry is looking for performance data derived from independent validation testing. The Video Quality Experts Group (VQEG) has become the primary forum for validation testing of objective perceptual quality models. The work of VQEG has resulted in International Telecommunication Union (ITU) standardization of objective quality models designed for standard definition television and, more recently, for multimedia applications. This article reviews the work of VQEG with particular consideration of the group's approach to validation testing, focusing on the recently completed Multimedia Phase I testing and the future agenda of VQEG.

Unpublished Presentations

A. Catellier, "Audio quality measurements and advances," presented at the University of Wyoming Student IEEE Meeting, Laramie, Wyoming, Apr. 2009.

R. T. Johnk and J. D. Ewan, "High-resolution site attenuation measurements using ordinary EMC antennas," presented at the Workshop on Advances in Site Validation Techniques and Related Measurement, IEEE EMC Symposium, Austin, Texas, Aug. 2009.

R. T. Johnk, "A mobile-to-mobile propagation study" Presented at the DoD E3 Program review, New Orleans, Louisiana, Mar. 2009.

J. Kub, "Dynamically creating and deleting map services and layers using VB.NET and ArcGIS Server," presented at the ESRI Developer's Summit, Palm Springs, California, Mar. 2009

J. Kub, "How to dynamically create an ESRI web-map using VB.NET/ASP.NET, and dynamically adding user selected layers to the map," presented at the GIS Developer Group meeting, Boulder, Colorado, Feb. 2009.

M. Ossmann and D. Spill, "Building an All-Channel Bluetooth Monitor" presented at ShmooCon, Washington, DC, Feb. 2009.

M. Ossmann, D. Spill, and M. Steward, "Bluetooth, smells like chicken," presented at DEF CON 17, Las Vegas, Nevada, Jul. Aug. 2009.

ITS Standards Work in FY 2009

Standards Leadership Roles and Membership in Standards Development Organizations

David J. Atkinson
Vice-Chair of the APIC Vocoder Task Group and Vice-Chair of the APIC Audio Performance Working Group, both affiliated with TIA TR-8.

Christopher J. Behm
Head of Delegation for Working Party 3L and delegate to WP3L and WP3K, ITU-R Study Group 3.

Randall S. Bloomfield
Vice-Chair of the ISSI Task Group (ISSI TG) within the APCO Project 25 Interface Committee (APIC); Convener of the P25 User Needs Subcommittee (P25 UNS); Editor of the Project 25 Statement of Requirements (P25 SoR).

John E. Carroll
Delegate to ITU-R Working Party 5B.

Carolyn G. Ford
Member of Video Quality Experts Group (VQEG), U.S. Delegate of ITU-T Study Group 9.

Paul M. McKenna
U.S. Chair of ITU-R Study Group 3 (Radiowave Propagation); Working Party 3J, 3K, 3L, and 3M; International Chair of Subgroup 3K-2.

Margaret H. Pinson
Associate Rapporteur for Question 12/9 (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); ITU-T Study Group 9 contact for Electronic Working Methods; Independent Lab Group member for Multimedia test and Co-chair of HDTV effort, Video Quality Experts Group (VQEG). Rapporteur in ITU-R WP6C for "Global video evaluation methodology landscape." Head of U.S. Delegation to ITU-T Study Group 9. Member of U.S. Delegation to ITU-R WP6C.

Patricia J. Raush
U.S. Co-chair of Working Party 3J; Head of Delegation for WP3J; delegate to WP3J, WP3K, WP3L, and WP3M.

Timothy J. Riley
Member of Alliance for Telecommunications Industry Solutions (ATIS) committee WTSC-RAN (Wireless Technologies and Systems Committee — Radio Access Networks) and issue champion and editor for development of a document addressing interference issues affecting wireless communication systems. Member of the U.S. delegation to ITU-R Working Party 5D (IMT Systems), ITU-R Study Group 5 (Terrestrial Services).

Teresa Rusyn
Member of Working Party 3K and 3M, ITU-R Study Group 3.

Frank H. Sanders
Chair of ITU-R Radar Correspondence Group (radar technical spectrum issues); Delegate to ITU-R Working Party 5B (radar spectrum allocation and sharing) and Joint Rapporteur Group 1A-1C-5B (radar spectrum efficiency issues).

Arthur A. Webster
International Chair of ITU-T Study Group 9 (Integrated broadband cable networks and television and sound transmission), and additionally SG9 contact for public relations, Rapporteur to ITU-T standardization committee for vocabulary (SCV), and representative to ITU-T Joint Coordination Activities such as those on Interoperability and Conformance and Identity Management (JCA-IDM, JCA-NID, and JCA-CIT); Co-chair of Video Quality Experts Group (VQEG); Co-Chair of Joint Rapporteur Group on Multimedia Quality Assessment (JRG-MMQA); Vice-chair of ATIS PRQC's Security Task Force. Member of U.S. Delegations to ITU-T Study Group 9, TSAG, ITU Council, and ITU-R WP6C.

Representative Technical Contributions

The contributions listed below are a sample of the extensive standards work that ITS does each year. More details of this work can be found in the individual write-ups throughout this report.

Emergency Telecommunications Service (ETS) Standardization

- "Framework for implementing preferential telecommunications in IPCablecom networks," ITU-T Recommendation J.261, February 2009 (A. Webster, L. Raman (SAICz), and G. Bain (NCS)).
- "Specifications authentication in preferential telecommunications over IPCablecom2 networks," ITU-T Recommendation J.262, February 2009. (A. Webster, L. Raman (SAIC), and G. Bain (NCS)).
- "Specifications for preferential telecommunications over IPCablecom2 networks," ITU-T Recommendation J.263, February 2009 (A. Webster, L. Raman (SAIC), and G. Bain (NCS)).
- "User-Network Interface (UNI) Media Plane Security Standard for Evolving VoIP/Multimedia Networks—Clean Text for LB submission," ATIS PRQC-2008-142, November 7, 2008. (A. Webster, M. Lee (Nortel), S. Jacobs (Protiro for ITS).
- "Media Plane Performance Security Impairments Standard for Evolving VoIP/Multimedia Networks," ATIS PRQC-2009-054R1, April 21, 2009 (A. Webster, S. Jacobs (Protiro for ITS), A. Nguyen (NCS)).

APCO Project 25

- APCO Project 25 Statement of Requirements, P25 UNS, Oct. 2008 (R. Bloomfield (Editor)).
- NIST/OLES Letter Ballot Comments on Draft TIA-102.CACA-1 (P25 ISSI Measurement Methods for Voice Services – Addendum 1 – Trunked Console ISSI), TR8.19, Oct. 2009 (B. Ward, N. Walowitz (Protiro for ITS), R. Bloomfield).
- NIST/OLES Letter Ballot Comments on Draft TIA-102.CACB-1 (P25 ISSI Performance Recommendations for Voice Services – Addendum 1 – Trunked Console ISSI), TR8.19, Oct. 2009 (B. Ward, N. Walowitz (Protiro for ITS), R. Bloomfield).
- NIST/OLES Letter Ballot Comments on Draft TSB-102.BBAA (P25 Two-Slot TDMA Overview), TR8.12, Nov. 2008 (R. Bloomfield).
- ITS Comments on 08-073 (P25 Interoperability Testing for Wide Area ISSI – Level 3 – Revision C), ISSI TG, Nov. 2008 (B. Ward, N. Walowitz (Protiro for ITS), A. Sharon (Protiro for ITS), E. Haakinson (Protiro for ITS)).
- P25 UNS Perspective Concerning Establishment of Priorities and Subsequently Undertaking Development of P25 6.25 kHz Equivalent Channel Requirements and Associated Standards, P25 UNS, Jan. 2009 (R. Bloomfield).
- Initial Proposal for P25 Wireless/Mobile Console Requirements, P25 UNS, Jan. 2009 (R. Bloomfield).
- High Level Work Plan to Address Project 25 6.25 kHz Equivalent Channel (Including 6.25 kHz FDMA) Issues, P25/34 Steering Committee, Jan. 2009 (R. Bloomfield).
- NIST/OLES Letter Ballot Comments on Draft TIA-102.BBAB (P25 Two-Slot TDMA Physical Layer Protocol Specification), TR8.12, Jan. 2009 (R. Bloomfield).
- ITS Comments on 08-095 (Draft P25 Trunked Voice Interoperability Test Procedures – Wide Area Operation Addendum), ISSI TG, Jan. 2009 (B. Ward, N. Walowitz (Protiro for ITS), A. Sharon (Protiro for ITS), E. Haakinson (Protiro for ITS)).
- RFSS/ISSI Upgrade Requirements Proposal, P25 UNS, Apr. 2009 (R. Bloomfield).
- Selected Considerations Regarding Development of New/Revised Requirements for RFSS Interconnection Using the ISSI, P25 UNS, Apr. 2009 (R. Bloomfield).
- Revision of P25 UNS Document Archiving Concepts for Discussion, P25 UNS, Apr. 2009 (R. Bloomfield).
- Submittal Memorandum to Steering Committee of 09-101 (Requirements Proposals Approved by P25 UNS at its April 30, 2009 Meeting), P25/34 Steering Committee, May 2009 (R. Bloomfield).

- ITS Comments on 09-031 (Draft P25 Two-Slot TDMA Media Access Control Layer Protocol Specification), TDMA TG, May 2009 (R. Bloomfield).

- ITS Comments on 09-060 (Draft P25 Interoperability Testing for Wide Area ISSI – Level 3 – Revision G), TR8.19, May 2009 (B. Ward, N. Walowitz (Protiro for ITS), E. Haakinson (Protiro for ITS)).

- ITS Comments on draft TIA-102 (Project 25 Systems and Standards Definition), Systems Task Group, Jun. 2009 (R. Bloomfield).

- NIST/OLES Letter Ballot Comments on Draft TIA-102.CACD (Interoperability Test Procedures for Trunked Systems Involving the ISSI), Jun. 2009 (B. Ward, N. Walowitz (Protiro for ITS), E. Haakinson (Protiro for ITS), R. Bloomfield).

- ITS Comments on 09-103 (P25 ISSI Interoperability Testing – Level 3 – Additional Test Cases – Rev H), ISSI TG, Jun. 2009 (A. Thiessen, B. Ward, N. Walowitz (Protiro for ITS), E. Haakinson (Protiro for ITS)).

- ITS Comments on 09-142 (P25 ISSI RCAT – Trunking ISSI – Revision C), ISSI TG, Jul. 2009 (B. Ward, N. Walowitz (Protiro for ITS), E. Haakinson (Protiro for ITS)).

- P25 UNS Agreements Reached at August 5, 2009 Teleconference for Modifying Conventional Talk Group Use and Hangtime Requirements, P25 UNS, Aug. 2009 (R. Bloomfield).

- ISSI Requirements Proposal Relative to P25 SoR Working Document (WD) Issue G Item 1, P25 UNS, Aug. 2009 (R. Bloomfield).

- P25 UNS Work Plan (August 23, 2009), P25 UNS, Aug. 2009 (R. Bloomfield).

- Editorial Changes to P25 SoR Approved on August 15, 2009 (09-125-R1), P25 UNS, Aug. 2009 (R. Bloomfield).

- APCO Project 25 Statement of Requirements, P25 UNS, Aug. 2009 (R. Bloomfield (Editor)).

- P25 SoR Working Document - Issue B, P25 UNS, Sep. 2009 (R. Bloomfield).

- ITS Comments on 09-188 (Draft P25 Interoperability Testing for Wide Area ISSI—Level 3—Revision K), TR8.19, Sep. 2009 (B. Ward, N. Walowitz (Protiro for ITS), E. Haakinson (Protiro for ITS)).

Video and Multimedia Quality

- "Proposed new Recommendation: Reference Algorithm for Computing Peak Signal to Noise Ratio (PSNR) of a Video Sequence with a Constant Delay (J.ra-psnr)," ITU-T Study Group 9 Contribution 6 (U.S.), Jan. 21, 2009 (S. Wolf and M.H. Pinson).

- "Proposed normative Annex in Draft New Recommendation J.redref: Fast Low Bandwidth Video Quality Model (VQM) Description and Reference Code," ITU-T Study Group 9 Contribution 5 (U.S.), Jan. 21, 2009 (S. Wolf and M.H. Pinson).

- "Reference algorithm for computing Peak Signal to Noise Ratio (PSNR) of a video sequence with constant delay," ITU-R Working Party 6C Contribution 243 (U.S.), Oct. 22, 2009 (S. Wolf and M.H. Pinson).

- "Perceptual visual quality measurement techniques for television broadcasting in the presence of a reduced bandwidth reference," ITU-R Working Party 6C Contribution 244 (U.S.), Oct. 22, 2009 (S. Wolf and M.H. Pinson).

- "Test Plan for Evaluation of Video Quality Models for Use with High Definition TV Content," Video Quality Experts Group, 2009 (M.H. Pinson, G. Cermak (Verizon), L. Thorpe (Nortel), et al.)

- "Considerations for Video Scene Selection" and "Audio-Video Experiments," presentations to Video Quality Experts Group, June 2009 (M.H. Pinson).

- "Validation of Reduced-Reference and No-Reference Objective Models for Standard Definition Television, Phase I," Video Quality Experts Group Final Report, 2009.

- "Video Quality Experts Group Update," ATIS PRQC-2008-137, November 3, 2008 (A. Webster).

Abbreviations/Acronyms

2D	two-dimensional
3D	three-dimensional
3G	third generation
4G	fourth generation

A

AAR	Association of American Railroads
AC	alternating current
ANS	American National Standard
ANSI	American National Standards Institute
AOA	Angles of Arrival
APCO	Association of Public-Safety Communications Officials—International
APD	amplitude probability distribution
APIC	APCO Project 25 Interface Committee
APWG	Audio Performance Working Group
ATC	air traffic control
ATCBI	air traffic control beacon interrogator
ATIS	Alliance for Telecommunications Industry Solutions
AUGNet	Ad hoc UAV Ground Network

B

BER	bit error rate
BPSK	binary phase shift keying
BVQM	Batch VQM

C

CAI	Common Air Interface
CAP	Compliance Assessment Program
CD	compact disk
CDA	Code Domain Analyzer
CDMA	Code Division Multiple Access
CIF	common intermediate format
CIP	Critical Infrastructure Protection
CMRS	Commercial Mobile Radio Services
CONUS	Continental U.S.
COTS	commercial off-the-shelf
CRADA	Cooperative Research and Development Agreement
CRPL	Central Radio Propagation Laboratory
CSPM	Communication System Performance Model
CSPT	Communication System Planning Tool
CSSI	Console Subsystem Interface
CU	University of Colorado
CVQM	Command Line VQM

D

DAT	digital audio tape
dB	decibel
DFS	Dynamic Frequency Selection
DHS	Department of Homeland Security
DOC	Department of Commerce
DOD	Department of Defense
DSA	Dynamic Spectrum Access
DSCP	Digital Sampling Channel Probe
DSES	Deep Space Exploration Society
DSR	Documentation Suite Reference
DTV	digital television

E

EIA	Electronic Industries Alliance
EMC	electromagnetic compatibility
ERP	effective radiated power
ESSA	Environmental Science Services Administration
ETS	Emergency Telecommunications Service

F

FCC	Federal Communications Commission
FDMA	Frequency Division Multiple Access
FEMA	Federal Emergency Management Agency
FLC	Federal Laboratory Consortium for Technology Transfer
FM	frequency modulation
FPGA	Field Programmable Gate Array
FPIC	Federal Partnership for Interoperable Communications
FTP	File Transfer Protocol
FTTA	Federal Technology Transfer Act 1986
FY	Fiscal Year

G

GAST	gradient ascent subjective testing
GETS	Government Emergency Telecommunications Service
GHz	gigahertz
GIF	Graphics Interchange Format
GIS	Geographic Information System

GLOBE	Global Land One-km Base Elevation
GPS	Global Positioning System
GUI	Graphical User Interface
GUC	Generalized Use Class

H

HATS	head and torso simulator
HD	high definition
HDTV	High Definition Television
HF	high frequency
HPGL	Hewlett-Packard graphics language

I

I/N	Interference to Noise
I/Q	in-phase/quadrature
IAA	interagency agreement
IAFC	International Association of Fire Chiefs
IBOC	in-band on-channel
ICEPAC	Ionospheric Communications Enhanced Profile Analysis and Circuit Prediction Program
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IF	intermediate frequency
ILG	Independent Lab Group
IMT	International Mobile Communications
INR	interfering signal to noise power ratio
IP	Internet Protocol
IPC	Interference protection criteria
IPTV	Internet Protocol Television
IRAC	Interdepartment Radio Advisory Committee
ISART	International Symposium on Advanced Radio Technologies
ISSI	Inter-RF Subsystem Interface
IT	information technology
ITM	Irregular Terrain Model
ITS	Institute for Telecommunication Sciences
ITSA	Institute for Telecommunication Sciences and Aeronomy
ITT	ISSI Test Tool
ITU	International Telecommunication Union
ITU-R	ITU — Radiocommunication Sector
ITU-T	ITU — Telecommunication Standardization Sector
IVQM	In-Service VQM

J

JCREW	Joint Counter Radio Controlled Electronic Warfare
JRG	Joint Rapporteur(s) Group
JRG-MMQA	Joint Rapporteur Group on Multimedia Quality Assessment

K

kHz	kilohertz
km	kilometer
kW	kilowatt

L

LADAR	Laser Detection and Ranging
LAN	Local Area Network
LB	Letter Ballot
LF	low frequency
LFMF	low frequency/medium frequency
LMCT	Lockheed Martin/Coherent Technologies
LMDS	Local Multipoint Distribution Service
LMR	Land Mobile Radio
LNA	low noise amplifier
LOS	line of sight
LTE	long term evolution

M

m	meter
MD	multimedia definition
MF	medium frequency
MHz	megahertz
MIMO	Multiple Input Multiple Output
MOS	Mean Opinion Score
MSC	message sequence chart
MSE	Mean Squared Error
MSTV	Association for Maximum Service Television

N

NARA	National Archives and Records Administration
NCS	National Communications System
NEC	Numerical Electromagnetics Code
NF	noise figure
NGN	Next Generation Network
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NR	no reference

NS/EP	National Security and Emergency Preparedness
NTIA	National Telecommunications and Information Administration
NWR	National Weather Radio
NWS	National Weather Service

O

OA	outside/other agency
OCIO	Office of the Chief Information Officer
OFDM	orthogonal frequency division multiplexing
OIC	Office of Interoperability and Compatibility (of DHS)
OLES	Office of Law Enforcement Standards
OMB	Office of Management and Budget
OQPSK	Offset Quadrature Phase-Shift Keying
OSM	Office of Spectrum Management
OT	Office of Telecommunications
OTP	Office of Telecommunications Policy

P

P25	Project 25
PASS	personal alert safety system
PBS	Public Broadcasting System
PC	personal computer
PCAP	packet capture
PCS	Personal Communications Services
PDA	personal digital assistant
PDD-63	Presidential Decision Directive No. 63 (on critical infrastructure protection)
PESQ	Perceptual Evaluation of Speech Quality
PIN	personal identification number
PLMR	private land mobile radio
PMW	Propagation Modeling Website
PN	pseudorandom number
PNT	positioning, navigation, and timing
PRQC	Network Performance, Reliability and Quality of Service Committee
PSAL	Public Safety Audio Laboratory
PSCR	Public Safety Communications Research
PSNR	peak signal to noise ratio
PSTN	Public Switched Telephone Network
PSVL	Public Safety Video Laboratory
PSVQ	Public Safety Video Quality
PTT	Push-to-Talk

Q

QoMEX	Quality of Multimedia Experience
QoS	Quality of Service
QPSK	Quadrature Phase-Shift Keying

R

R&D	research and development
RAID	redundant array of independent disks
RC	radio-controlled
RCAT	recommended compliance assessment tests
RCG	Radar Correspondence Group
RF	radio frequency
RFSS	Radio Frequency Subsystem
RNSS	Radionavigation Satellite Service
RR	reduced reference
RR-NR	Reduced Reference—No Reference
RSEC	Radar Spectrum Engineering Criteria
RSMS	Radio Spectrum Measurement Science
RSMS-4G	4th Generation RSMS
RTP	Real-time Transport Protocol
RTSA	Real Time Spectrum Analyzers

S

S&E	salaries and expenses
S&T	Science & Technology
SCBA	self-contained breathing apparatus
SCTE	Society of Cable Telecommunications Engineers
SD	Standard Definition
SDMA	Space Division Multiple Access
SDO	Standards Development Organization
SDR	software defined radio
SDTS	Spatial Data Transfer Standard
SG	Study Group
SIP	Session Initiation Protocol
SIPRNET	Secret Internet Protocol Routable Network
SISO	single input, single output
SoR	Statement of Requirements
SPF	Space Power Facility
SPIE	the international society for optics and photonics
SV	Systems View

T

TA Services	Telecommunications Analysis Services
TDMA	time division multiple access
TDWR	Thermal Doppler Weather Radar
TG	Task Group

TIA	Telecommunications Industry Association
TIREM	Terrain Integrated Rough Earth Model
TM	Technical Memorandum
TOV	threshold of visibility
TR	Technical Report
TR-8	Personal and Private Land Mobile Radio (a TIA standards development committee)
TSB	Telecommunications Systems Bulletin
	Technical Service Bulletin
TV	television

U

UAV	unmanned aerial vehicle
UHF	ultra high frequency
UK	United Kingdom
UNI	User-Network Interface
U-NII	Unlicensed National Information Infrastructure
UNS	User Needs Subcommittee
U.S.	United States
USGS	U.S. Geological Survey

V

VFD	Variable Frame Delays
VHF	very high frequency
VoIP	Voice over Internet Protocol
VQEG	Video Quality Experts Group
VQM	Video Quality Metric
VSA	vector signal analyzer
VSG	vector signal generator
VQiPS	Video Quality in Public Safety (conference)

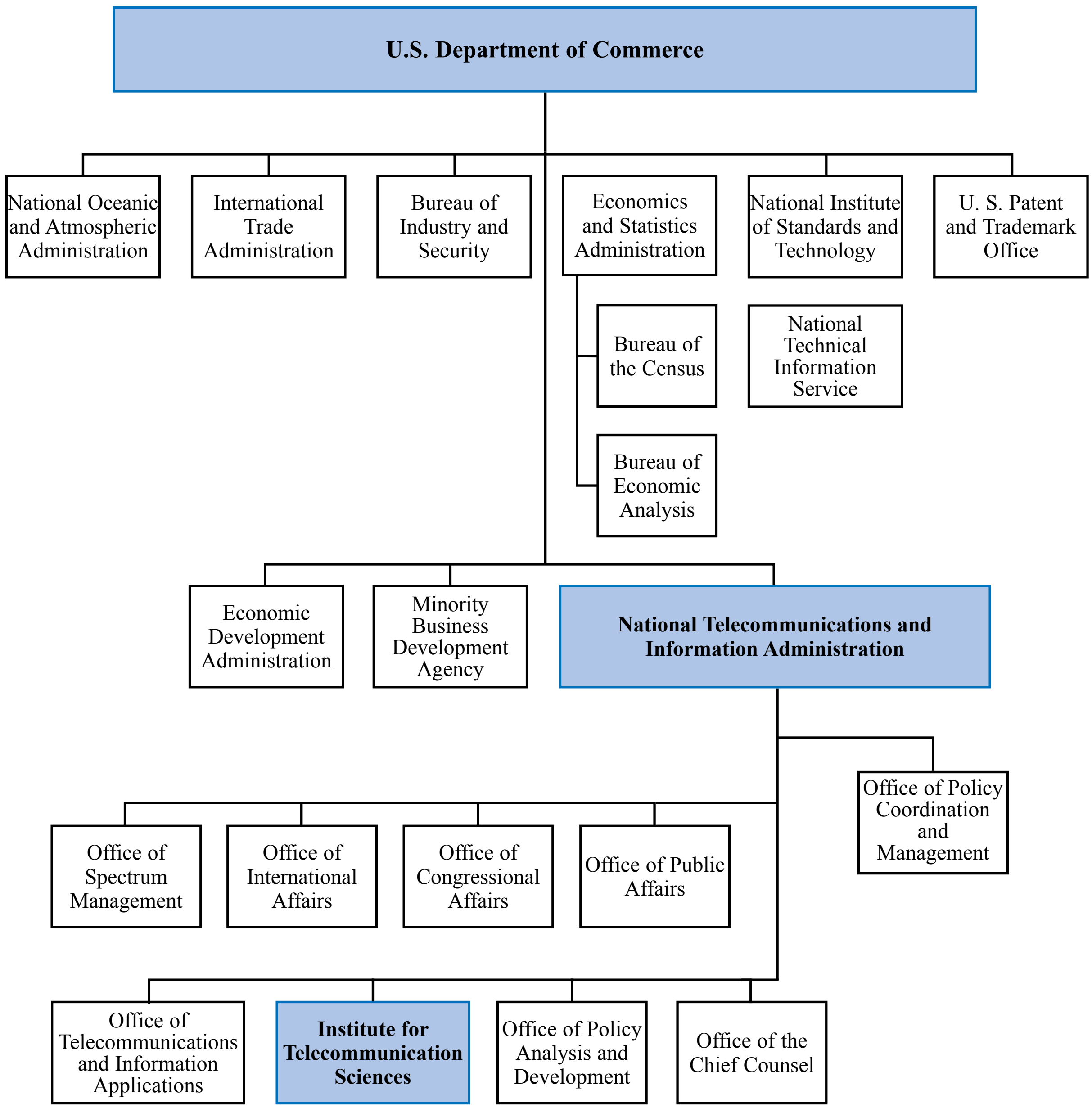
W

W	watt
WB	wideband
WCC	Wireless Communications Committee
W-CDMA	Wideband CDMA
WD	working document
WG	working group
Wi-Fi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WNRC	Wireless Networks Research Center
WP	Working Party
WTSC-RAN	Wireless Technologies and Systems Committee - Radio Access Networks

Y

YIG	yttrium-iron-garnet

DOC/NTIA Organization Chart



DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA