Institute for Telecommunication Sciences

2004 Technical Progress Report

U.S. Department of Commerce
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for Communications and Information

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

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Winter day behind the Boulder Labs (photograph by G.R. Hand).

The ITS Mission

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

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

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

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

Autumn morning behind the Boulder Labs site (photograph by R. Hoffman).

Overview

The Institute for Telecommunication Sciences (ITS), located in Boulder, Colorado, is the research and engineering arm of the National Telecommunications and Information Administration (NTIA) of the U.S. Department of Commerce. The Institute's staff, all of whom are Federal employees, provide strong engineering and scientific skills and experience to our technical programs. The majority of our employees are electronics engineers, but the staff also includes mathematicians, physicists, computer scientists, and specialists in other fields. ITS' support during Fiscal Year 2004 consisted of $6 million of direct funding from the Department of Commerce and approximately $8 million for work sponsored by other Federal agencies and U.S. industry.

History

ITS began in the 1940s as the Interservice Radio Propagation Laboratory, which after the war became the Central Radio Propagation Laboratory (CRPL) of the National Bureau of Standards, 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 two labs: the Aeronomy Laboratory and the Institute for Telecommunication Sciences (ITS).

In 1970, Executive Order 11556 established the Office of Telecommunications (OT) within the Department of Commerce and the Office of Telecommunications Policy (OTP) in the Executive Office of the President; at the same time, ITS was transferred from ESSA to OT. Under the President's Reorganization Act #1 of 1977, OT and OTP merged to form NTIA.

Since 1978, ITS has performed telecommunications research and provided technical engineering support to NTIA, and to other Federal agencies on a reimbursable basis. Over the last 15 years, ITS has pursued cooperative research with U.S. industry under the provisions of the Federal Technology Transfer Act of 1986. In 2004, ITS joined with NIST and NOAA to celebrate 50 years in Boulder.

Our Expertise

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

Our Facilities

The Institute's world-class facilities include:

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

The Benefits Created by ITS

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

- **Spectrum Utilization:** Optimization of Federal spectrum allocation methods, identification of unused frequencies and potential interference through field measurements, and promotion of technology advances to aid in efficient use of the spectrum.

- **Telecommunications Negotiations:** Expert technical leadership at international conferences and development of negotiation support tools such as interference prediction programs.

- **Public Safety:** Systems engineering, planning, and testing of interoperable radio systems (e.g., voice, video, and data) for the use of "first responders" at the Federal, State, local, and tribal levels.

- **National Defense:** Improvement of network operation and management, enhancement of survivability, expansion of network interconnections and interoperation, and improvement of emergency communications that contribute to the strength and cost-effectiveness of the U.S. Armed Forces.

- **Domestic Competition:** Development of user-oriented, technology-independent methods of measuring telecommunications performance to give users a practical way of comparing competing equipment and services.

- **International Trade:** Promulgation of international telecommunications standards to remove technical barriers to U.S. export of telecommunications equipment and services.

- **Technology Transfer:** Direct transfer of research results and measurements to U.S. industry and Government to support national and international competitiveness, bring new technology to users, and expand the capabilities of national and global telecommunications infrastructures.

Our Organization

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

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

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

Our Sponsors

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

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

Because of its centralized Federal role, ITS can provide a cost-effective, expert resource that supports many Federal agencies and industry organizations. ITS provides research and engineering that is critical to continued U.S. leadership in providing telecommunications and information equipment and services. This Progress Report summarizes technical contributions made by ITS during Fiscal Year 2004 to both the public and private sectors.

ITS engineers performing measurements on the ITS antenna range at the Table Mountain field site (photograph by J.D. Ewan).

Spectrum and Propagation Measurements

The radio spectrum is a natural resource that offers immense benefit to industry, private citizens, and government by supporting a wide range of radio and wireless applications for communications and sensing. Unlike many other natural resources, the spectrum is non-depleting so it can be used indefinitely. However, the rapidly increasing number of radio devices and active competition for improved access to the radio spectrum suggests that its effective use will require increasingly more complex knowledge of the existing signals environment, as well as an understanding of the technical and operational factors that can cause interference between systems that share the spectrum.

NTIA manages the Federal Government's use of the spectrum to ensure maximum benefit to all users while accommodating additional users and new services. Efficient and effective use of the spectrum is a key element in both the NTIA and the ITS missions.

The Spectrum and Propagation Measurements Division of ITS performs measurements and analysis of radio signals to support research and engineering enabling more efficient and effective use of the spectrum. In addition to a well-equipped research laboratory, major tools include the Radio Spectrum Measurement System (RSMS), a van full of very capable computer-controlled radio measurement devices, and the Table Mountain Field Site and Radio Quiet Zone.

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

Areas of Emphasis

Radio Spectrum Measurement System (RSMS) Operations
The Institute uses the RSMS to perform measurements of emission characteristics of new or proposed systems, of spectrum occupancy to determine the level of crowding, of EMC characteristics, and to resolve interference problems. The project is funded by NTIA.

RSMS-4 Development
The Institute is developing the next generation measurement hardware and software capabilities to provide RSMS-4 systems with greatly improved measurement and digital signal processing capabilities. System software will provide very flexible control, remote monitoring, uniform data recording and storage, and powerful analysis and display routines. The project is funded by NTIA.

Table Mountain Research
The Institute uses the facilities at an 1800-acre radio quiet zone to perform a wide range of critical spectrum measurements and research. This year such research has included methods for measuring and analyzing background noise, new antenna development, and detailed radar measurements. The project is funded by NTIA.

Spectrum Efficiency Research
The Institute investigates ways that Federal agencies can make more efficient and effective use of the spectrum to accomplish their respective missions. Recent work includes evaluating the use of the 162-174 MHz band by Federal agencies in the Washington, DC, area to assess the hypothetical merits of moving separate Federal mobile radio systems onto various common shared radio systems. This work is funded by NTIA.

Signals, Emission, and Performance Measurements
The Institute studies the signals generated by both existing and proposed new communication systems, develops methods for characterizing these signals, and evaluates the effects that certain signals may have on specific victim receivers. Projects this year have included the development of performance metrics and measurements for the NOAA Weather Radio system, and investigation into the effects of various ultrawideband (UWB) signals on wideband receivers. This work is funded through reimbursable agreements with other government agencies, and cooperative research and development agreements (CRADAs) with private industry.

Radio Spectrum Measurement System (RSMS) Operations

Outputs

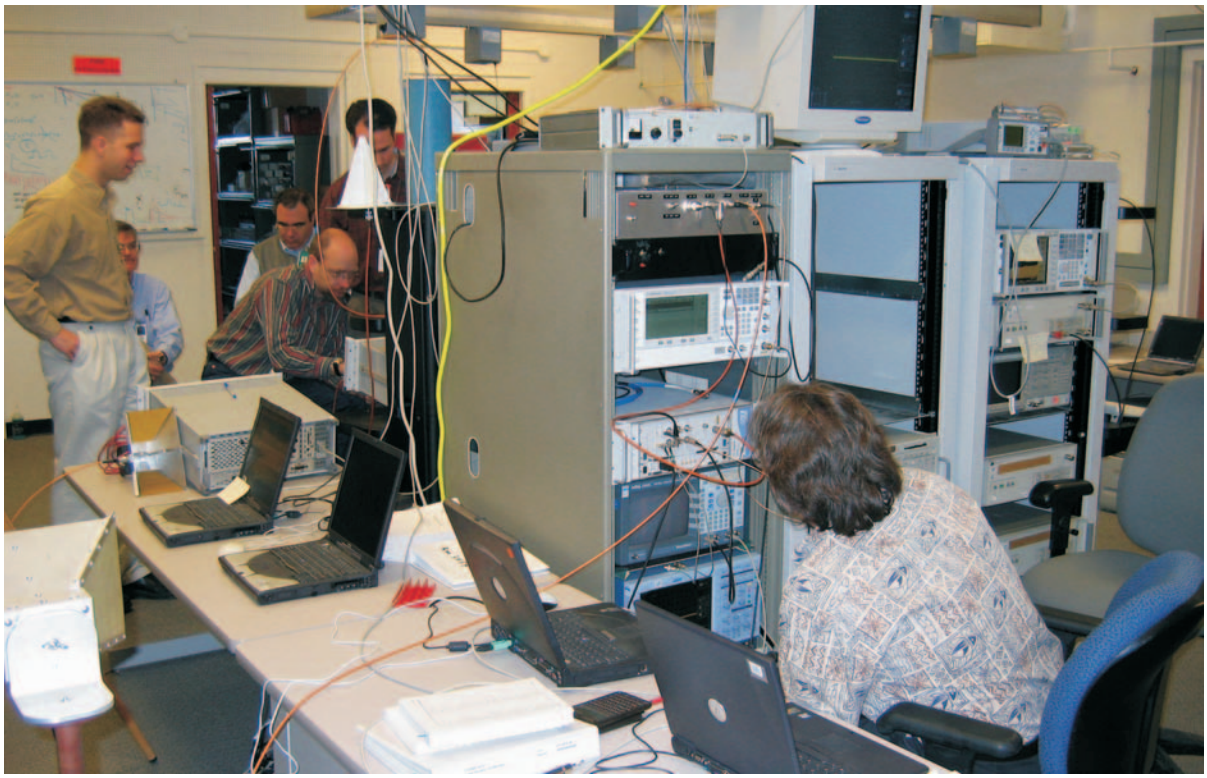
- Measurements to determine radio emission levels from broadband over power lines.
- Measurements to determine move-times and detection thresholds of dynamic frequency selection (DFS) devices.
- Measurements to determine the nature and extent of interference disrupting operations of an Air Force S-band satellite earth station receiver downlink.
- Measurements to determine radionavigation satellite service (RNSS) compatibility with radiolocation services in the 1260-1300 MHz band.

The Radio Spectrum Measurement System (RSMS) is a collection of equipment, measurement routines, and qualified personnel for performing critically needed radio signal measurements necessary for making decisions regarding Federal Government spectrum allocations. As stated under Departmental Organization Order 25-7, issued 5 October 1992, and amended 3 December 1993, the NTIA Office of Spectrum Management (OSM) is responsible for identifying and making arrangements for measurements necessary to provide NTIA and the various departments and agencies with information to ensure effective and efficient use of the spectrum. The RSMS resides at ITS in Boulder, and is tasked to perform measurements in support of OSM as required to fulfill their mission. ITS, through the RSMS Operations project, provides OSM and the executive branch with critically needed radio spectrum data, data analysis, reports, and summaries. Four basic areas of RSMS measurement are 1) spectrum surveys and channel usage, 2) equipment characteristics and compliance, 3) interference resolution and compatibility and 4) signal coverage and quality. In FY 2004, several different measurements were performed throughout the year in support of the basic mission.

In October of 2003, ITS personnel performed, as part of an ongoing effort, measurements to determine the radio emission levels from broadband over power lines (BPL). BPL is a new technology that transforms power lines into network cables that can deliver broadband content. BPL is transmitted over an unshielded medium, so the RSMS was used to perform measurements to determine the nature and extent of radiating fields due to this new technology. Three field measurements, each lasting approximately 2 weeks, were first conducted in late FY 2003 and then again in the early part of FY 2004. In conjunction with that work, modeling of the power lines was performed to describe the skyward radiation and the radiation that a mobile receiver would experience. The modeling was used to make predictions that were not easily accomplished by measurements alone. The measurement results and modeling were summarized and provided to OSM, the content of which were included in NTIA Report 04-413 (see Recent Publications below) as a response to an FCC notice of proposed rule making.

In January and April of 2004, laboratory measurements were conducted to determine move-times and detection thresholds of dynamic frequency selection (DFS) devices. DFS is a method whereby radio local area network (RLAN) devices, using the 5 GHz band for unlicensed operations, will detect the operations of radar and promptly evacuate the channel if the radar is present. Measurements were conducted to determine if current DFS devices comply with specifications given in ITU-R M.1658. This testing was used to support NTIA's comments and reply comments to the FCC UNII rule-making (FCC Docket 03-122). ITS support consisted of developing a radar signal simulator, developing testing algorithms, and performing the measurements.

In March of 2004, additional measurements were performed on various ultrawideband (UWB) modulations to validate existing bandwidth correction factor (BWCF) models. UWB is the term applied to very narrowly pulsed signals in which spectral emissions have an instantaneous bandwidth of at least 25% of the center frequency. For those who make policies regarding UWB emissions, it is worthwhile to know, when a certain signal with certain spectral characteristics is measured in one bandwidth, what the power is at another bandwidth. Different pulse spacing modulations of UWB signals result in different spectral characteristics. Focusing on the regions



Dynamic frequency selection compliance measurements performed at ITS (photo by J.R. Hoffman).

where the measurement bandwidth is equal to ½ the pulse repetition frequency (PRF) of the UWB signal, the purpose of the BWCF measurements was to examine the relationship between bandwidth and mean power for several representative UWB modulations. The results were used in compatibility analyses of UWB transmission systems and Federal radiocommunication systems.

In April 2004, ITS was called on to determine the nature and extent of interference that was disrupting operations of an Air Force S-band satellite earth station receiver downlink. Based upon preliminary tests performed at the facility by the Air Force, a correlation had been observed between the interference noted in the satellite receiver and the presence of an apparent spurious emission from the video carrier of a local television station. Measurements using the RSMS were conducted over the course of a week to determine the source of the interference. Results were provided to the Air Force summarizing the source of interference.

In June 2004, measurements were conducted to determine radionavigation satellite service (RNSS) compatibility with radiolocation services in the 1260-1300 MHz band. This work was in support of OSM, as well as the U.S. Administration in ITU-R Working Party 8B. The measurements determined and documented the jamming effects on this type of radar when (and if) the satellite signals in question are ever activated. The tests, which were done in coordination with the FAA, included jamming of actual aircraft blips as traffic was being tracked.

Measurements to determine Land Mobile Radio adjacent channel rejection characteristics were conducted for several months starting May 2004. These measurements are in support of an ongoing project to upgrade the sharing procedures described in Annex I of the NTIA manual.

Recent Publication

B. Bedford, A. Paul, and J. Richards, “Potential interference from broadband over power line (BPL) systems to Federal Government radiocommunications at 1.7 – 80 MHz: Phase 1 Study,”NTIA Report 04-413, Apr. 2004.

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RSMS-4 Development

Outputs

- Functional data acquisition and system control software.
- Integrated measurement system — including spectrum analyzers, digital oscilloscopes, vector signal analyzers, and signal detection devices.
- Fully operational RSMS 4th generation measurement vehicle.

The 4th generation Radio Spectrum Measurement System (RSMS-4) consists of state-of-the-art tools for making measurements to characterize spectrum occupancy, ensure equipment compliance, determine electromagnetic compatibility, and analyze interference problems. The development of RSMS-4 originated out of the need to upgrade to the latest technology used in RSMS operations. RSMS operations directly supports NTIA by providing critical measurement support for determining policies affecting both the public and private sectors. The following new capabilities have been added to the system.

SOFTWARE: The RSMS-4G software has an open-ended architecture that allows nearly unlimited expansion and flexible system configurations. Integral to this flexible architecture are instrument and measurement dynamic link libraries (DLLs).

DLLs have been developed on several key pieces of measurement equipment (including several spectrum analyzers, oscilloscopes, VSAs, modulation domain analyzers, and preselectors). These DLLs contain carefully defined command/query modules that interpret commands common to the different equipment categories. Also included is a Virtual Panel that provides a user friendly graphical interface for manually controlling the device from the computer. So as to standardize their use, each DLL, in turn, has a general instrument interface common to all measurement devices. These DLLs, when completed, provide access for rapid development of automated measurements.

DLLs have also been developed for several different automated measurement procedures. These “Measurement” DLLs also have a user friendly graphical interface for setting up and monitoring the progress of a measurement. Common to all “Measurement” DLLs is a carefully defined interface so that their use can be standardized. Three of these measurement routines were used extensively during the broadband-over-power-line measurements — a calibration procedure, a stepped frequency measurement, and an amplitude probability distribution (APD) measurement. A newly designed Land Mobile Radio (LMR) channel occupancy measurement was utilized during measurements in Washington, DC, this fall (see photo). In addition, a stepped frequency APD measurement has been developed, and an automated swept frequency measurement is in the works.

Features added to the software in FY 2004 include the system configuration module and the preselector manager. The system configuration module provides the user with an easy-to-use graphical interface for designating the configuration and making the control connections to the various instruments in the measurement system. Included is a device database where instrument and discrete device specifications are stored. The preselector manager integrates any and all preselectors in the system so that the measurements simply need to designate a frequency without knowledge of path characteristics.

HARDWARE: Several new pieces of equipment, all of which provide improvements and/or new capabilities, have been added to the already extensive inventory of measurement tools.

- Four spectrum analyzers with powerful digital signal processing capabilities that provide features never before possible in older models.
- Two vector signal analyzers (VSAs) that allow digitization with a bandwidth of 36 MHz, and a instantaneous dynamic range of 90 dB. Included is a suite of software capabilities that allow complex signal analysis and demodulation.
- Two VXI-based signal intercept and collection systems that allow digital acquisition when signals meet specified characteristics and can be used to trigger digitization and analysis by the VSAs. Also included are high speed digital signal processing chips that can be programmed using open-architecture software.
- Two quad input digital oscilloscopes with a front-end bandwidth of 500 MHz and maximum sampling rate of 4 GS/s. Also included are

Radio Spectrum Measurement System (RSMS) 4th generation vehicle performing Land Mobile Radio channel occupancy measurements in the Washington DC area. (photograph by B.L. Bedford).

special smart-triggering capabilities and segmented memory. The latter makes for efficient acquisition of pulsed signals with small duty cycles.

- One wide-bandwidth digital oscilloscope with a front-end bandwidth of 1 GHz and maximum sampling rate of 5 GS/s. This device has specialized peak and sample detection capabilities making it suitable for wide bandwidth acquisition and analysis — including pulsed signals.
- Three new custom-built preselectors that filter and amplify the desired signals. A new flexible configuration preselector was used extensively in recent land mobile radio channel occupancy measurements.

VEHICLE: The following added features in the new measurement vehicle make it possible to perform measurements efficiently and effectively.

- The enclosure has 60 dB effective shielding from all points, making this vehicle particularly suited for measurements in strong signal environments, as well as for noise measurements.
- Internet connections and routers are located throughout the enclosure. There are fiberoptic control lines, multiple power outlets, overhead cable racks, and 3 full instrument racks.
- There are both internet and shore power connections on the outside of the enclosure.
- Racks can be moved forward for rear access, locked into place, or removed entirely.
- There is plenty of counter space, storage space, and head room.
- The enclosure has three 10-meter masts — two in the rear and one in the front.
- There is easy enclosure entry, including retractable staircase with handrails.
- Extra brackets on the roof make it easy to mount antennas.
- The enclosure is powered by a 20 kWatt diesel generator capable of handling demands. for power from full equipment racks — plus air conditioning, and lighting.
- Both air conditioning and heating allow for enclosure temperature control in extreme weather conditions.
- The vehicle is powerful, easy-to-handle, and has sleeping space in the cab.

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Table Mountain Research

Outputs

- Comparison of measured automotive antenna patterns with computer simulations.
- Development of "ITS Interference Test Bed," used to generate and analyze complex signals.
- Development of a 3-axis antenna to study the total incident field and polarization of a signal.
- Radar testing for the ITU-R.
- Cooperative research and development agreements with several private companies for work at the Table Mountain Field Site.

The Table Mountain Field Site and Radio Quiet Zone (see p. 67) supports fundamental research into the nature, interaction, and evaluation of telecommunication devices, systems, and services. To achieve this goal, the Table Mountain Research project actively solicits research proposals from both inside the Institute as well as from external agencies. This research serves to expand the knowledge base available to the Institute, helps identify emerging technologies, and provides for the development of new measurement methods needed to study the characteristics of new devices and systems based on this technology. The results of the Table Mountain work are disseminated to the public via reports, technical papers, journal articles, conference papers, web documents, and computer programs. Highlights of the technical program are presented below.

Comparison of Measured Automotive Antenna Patterns with Computer Simulations

An antenna on a vehicle in a roadway environment does not behave as if it were in free space or over a perfectly conducting ground plane. The gain of the antenna is a function of the antenna geometry, materials used, antenna height above ground, ground conductivity, ground dielectric constant, frequency, elevation angle, and azimuth angle. The performance of an antenna near or on the surface of the earth is also very dependent on the interaction with the lossy earth and the automotive vehicle. Since antennas are commonly mounted on automobiles, an understanding of their performance in this environment is important for police, public safety, military, and commercial applications. This study was undertaken to provide a comparison between real-world measurements of antennas mounted on vehicles and computer simulations of these antennas.

Figure 1. Automotive antenna pattern study at the Table Mountain field site (photograph by J.D. Ewan).

For this study, antenna patterns and gains were measured at the Table Mountain Turntable Antenna Range at multiple frequencies from 41 to 918 MHz. Azimuth antenna patterns at several low elevation angles were measured using the azimuthal rotation of the turntable at multiple receiver antenna heights using a receiver antenna on a tower at a distance from the turntable. Simulation of these measurement scenarios will be completed in FY 2005 and the results will be compared.

The "ITS Interference Test Bed"

ITS is often called upon to evaluate the likelihood that a signal will interfere with a victim receiver. However, testing the effects of planned or proposed signals is complicated, since the transmitters for generating these signals may not yet exist or may only exist as prototype systems with limited availability or functionality. To work around this problem, ITS has developed a new "Interference Test Bed" that can be used to simulate any existing or planned signal without the development of specialized, one of a kind, signal generating hardware. This system also includes new digital analysis equipment that expands measurement and analysis beyond the capabilities of the traditional spectrum analyzer.

Development of a 3-Axis Antenna

Radio receiving antennas are designed to provide their maximum response to signals having specific polarizations and directions of arrival. These features are useful when designing communication systems that require reception of wanted signals and rejection of unwanted, interfering signals. In this case, we usually have some knowledge about the signal we want to detect. However, when performing spectrum surveys we often have little prior knowledge about existing signals, and are more interested in discovering what signals exist. For this case, we desire an antenna that is sensitive to signals incident from any direction and with any polarization.

The Table Mountain Research project has constructed a prototype antenna (see Figure 2) that uses three orthogonally mounted dipoles to sample the electromagnetic field. From this information it should be possible to compute the total RF field incident on the antenna as well as the polarization of the signal. Preliminary testing of this prototype looks promising. Work continues to characterize the antenna's response, and to develop the instrumentation and signal processing needed.

Radar Testing

This year the Table Mountain Field Site was used to provide critical support to the administrations of the United States and Japan through collaborative work in association with the ITU-R Joint Rapporteur Group (JRG) 1A-1C-8B and Working Party 8B (WP-8B). Data were gathered on emission spectra, antenna patterns, and pulse waveforms from a variety of S-band (3000 MHz) and X-band (9400 MHz) maritime navigation and surface search radars. The Table Mountain facility provided an ideal location for such measurements, combining the features of open, flat terrain; a radio-quiet environment; support facilities for measurement equipment and crews; and easy access from the Boulder laboratory. Five maritime radars shipped from Japan were measured at Table Mountain over a period of two weeks (see photos, pp. 57 and 70). The emission data were subsequently used by both governments to support their activities in the JRG and WP-8B. It is anticipated that similar measurements will be performed on other radar transmitters at Table Mountain in the future.

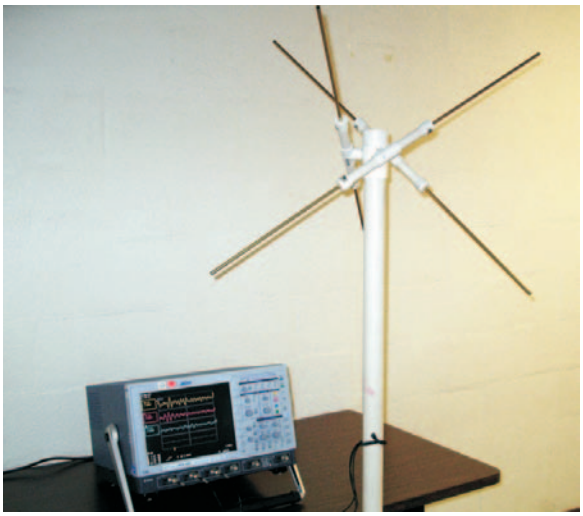

Figure 2. Prototype 3-axis antenna (photo by F.H. Sanders).

Cooperative Research and Development Projects at Table Mountain

- FirstRF Corporation
- RF Metrics Corporation
- Savi Technologies, Inc.
- Spectrum Mapping, LLC
- University of Colorado: Ad Hoc UAV and Ground Networking (AUGNET) research group

Recent Publication

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

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Spectrum Efficiency Research

Outputs

- Report on Federal LMR systems in the Washington, DC, area.
- White paper on spectrum efficiency concepts.
- Consultation with OSM on spectrum efficiency planning.

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

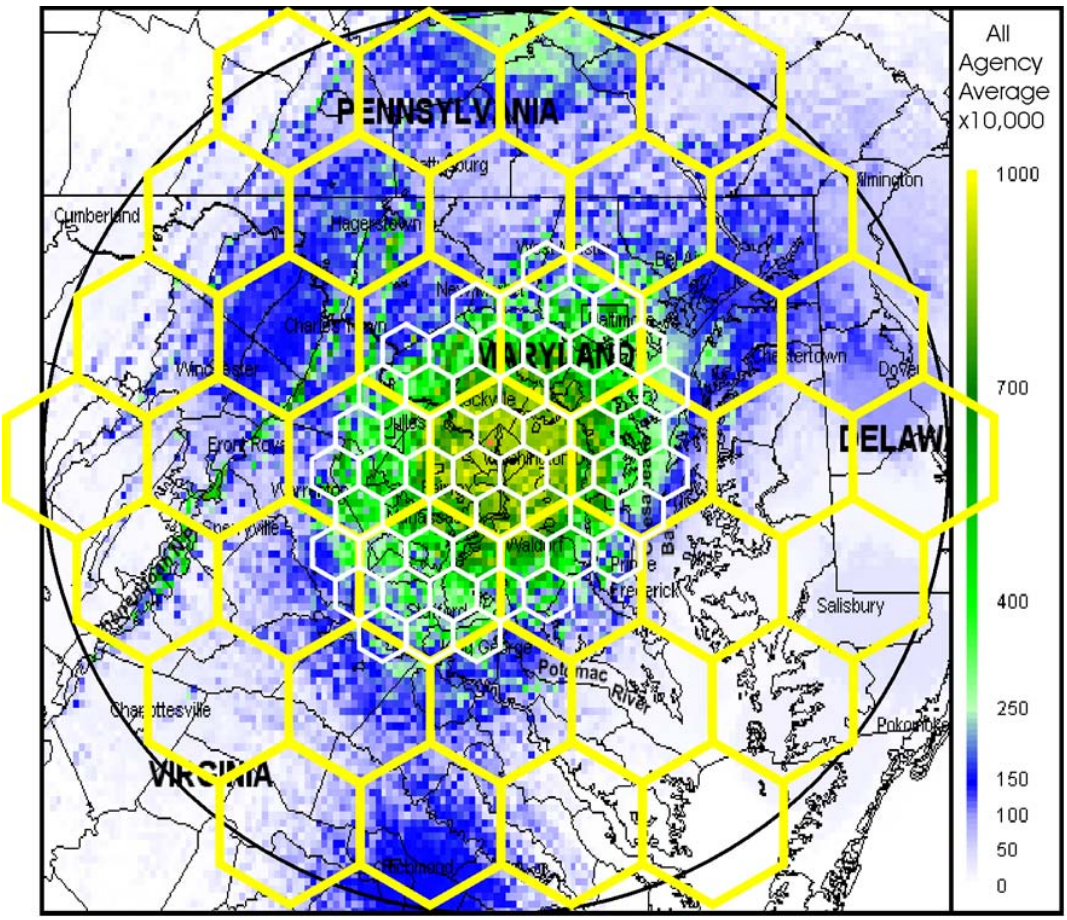
ITS is working with OSM to develop theoretical concepts and practical applications of improved spectrum efficiency. A problem is that "spectrum efficiency" can mean many things — some of them contradictory — and ITS has been active in helping to sort out concepts that will be useful in guiding Federal policies toward more effective use of the radio spectrum. During FY 2004, ITS prepared an initial paper on Spectrum Efficiency Concepts to guide discussion on some of the problematic aspects of spectrum efficiency that needed to be resolved to help NTIA develop improved policies and practices.

In related work, ITS is currently examining possible metrics (i.e., equations) that describe the spectrum efficiency of several types of radio services. This work will serve partly as a "reality check" to show whether it is practical to routinely and rigorously compute the spectrum efficiency of existing or proposed Federal radio systems.

ITS has been assisting in a modeling effort to see whether the current myriad of single-agency Federal mobile radio systems in the Washington, DC, area could be efficiently replaced by one large shared trunked radio system. The first part of this work was completed last year, including an NTIA Report (see Recent Publications below). This work investigated the current Federal land mobile radio (LMR) systems in the vicinity of Washington, DC. A major part of this study was to develop a signal capacity (SC) model that counted the number of independent radio signals available to a mobile user on a geographical basis, using the Government Master File (GMF) of Federal radio licenses as a source of detailed data. The SC model was developed to provide a combined geographical coverage "footprint" of the multiple independent existing radio systems now serving Federal Agencies. The SC model showed that as many as 268 separate LMR radio channels were available to a mobile user in the downtown Washington area in the 162-174 MHz band, as well as summarizing the current geographical coverage that a future shared trunked system would need to duplicate.

The other major input to a model for the design of future LMR systems was the measurement of actual LMR traffic (Erlangs) in the Washington area, using the ITS Radio Spectrum Measurement System (RSMS). These measurements were completed in November 2004, and the results will be used to describe the total amount of traffic that a future shared radio system should be designed to handle.

The design of future alternative shared LMR systems will be based on the SC geographical coverage data and the RSMS measured traffic data. The figure shows the average signal capacity (ASC) map for Washington, DC, overlaid with a 100-mi radius circle. The ASC map shows the number of independent radio systems per square mile (actual ACS values are multiplied by 10,000 on the map). This ASC data will be used to design several generic types of trunked radio systems, whose 20-mi radius coverage areas are shown as the large yellow hexagons. Two other generic trunked systems will use a combination of large-coverage cells in the outlying areas and two sizes of small-coverage cells (smaller white



Average signal capacity map for all Federal agencies within 100 miles of Washington, DC, overlaid with generic mobile radio base station coverage areas.

hexagons) in the central metropolitan areas. These three generic designs will be evaluated using four assumptions about the total number of users participating in the shared system, including traffic levels equivalent to 30%, 100%, 300%, and 1000% of the current RSMS-measured traffic levels. The final report is expected to evaluate each of the three system architectures under the conditions of the four traffic loading assumptions. These studies will provide useful insights for how the advantages of large shared trunked systems would be expected to scale for a range of alternative system architectures and operational scenarios.

Recent Publications & Presentations

G. Patrick, et al., "Spectrum effectiveness initiative: Phase 1 — Study of Federal operations in the 162-174 MHz band in the Washington, DC area," NTIA Report 04-415, in progress.

G. Patrick, C. Hoffman, and R. Matheson, "Signal capacity modeling for shared radio system planning," in "Proceedings of the International Symposium on Advanced Radio Technologies: March 2-4, 2004," J.W. Allen, T.X Brown, D.C. Sicker, and J. Ratzloff (Eds.), NTIA Special Publication SP-04-409, Mar. 2004, pp 77-86.

R. Matheson, "Alternative spectrum management techniques," tutorial presented at the International Symposium on Advanced Radio Technologies, Mar. 2004.

R. Matheson, "Spectrum measurements," invited presentation at the National Academy of Sciences, Committee on Wireless Technology Prospects and Policy Options, San Diego, Jul. 22, 2004.

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Investigation into Interference Potential of Ultrawideband Signals

Outputs

- Methods developed and measurements performed to determine UWB interference susceptibility of C-band satellite digital television receivers.
- Measurements performed to determine the effects of gating on the interference potential of Gaussian noise.
- Comparative measurements and analysis of DS-UWB and MB-OFDM signals.
- IEEE 802.15.3a standards contribution.

On March 22, 2004, ITS entered into a cooperative research and development agreement with Motorola/ Freescale Inc. A primary goal of this research is to identify characteristics of various ultrawideband (UWB) waveforms that correlate with performance degradation of legacy victim receivers.

UWB interference provides a unique challenge for spectrum policy makers. Narrow pulses, inherent to "conventional" UWB signals, spread power across a frequency band that can simultaneously cover operational bands for a number of victim receivers. UWB proponents have argued that UWB power spectral density is below the noise threshold of narrowband receivers and therefore causes little interference. UWB opponents argue that proliferation of UWB consumer devices will create a significantly degraded radio environment due to increased power spectral density of aggregate UWB interference and increased probability of encountering UWB devices.

In 2002, the Federal Communications Commission permitted low-power UWB emissions between 3.1 GHz and 10.6 GHz. The rules require that UWB signals have a 10-dB bandwidth greater than 500 MHz and greater than 25% of the center frequency without specifying how that bandwidth is achieved (i.e., which modulation is used). Consequently, these regulations expanded the scope of UWB to include modulations with defined carriers and band-limited pulses in addition to "conventional" carrier-less UWB signals.

An example of the increased scope of UWB is the development of the multi-band orthogonal frequency-division multiplexing (MB-OFDM) technology for short range, high data rate wireless communications. MB-OFDM achieves the ultra-wide bandwidth criteria with a 528-MHz wide OFDM signal that hops between 14 different bands. Direct-sequence ultrawideband (DS-UWB) is another technology recently developed for short-range wireless communications that combines conventional spread spectrum techniques and pulse shaping. Figures 1 and 2 illustrate amplitude statistics of simulated DS-UWB and MB-OFDM signals in various limiting bandwidths.

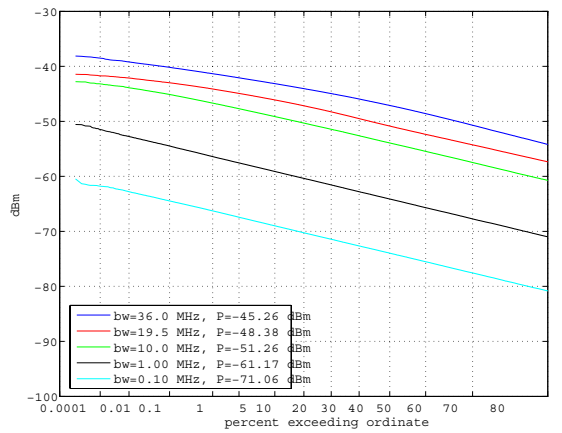

Figure 1. Amplitude statistics of DS-UWB (code = 0, -1, -1, -1, 1, 1, 1, -1, 1, 1, -1, 1).

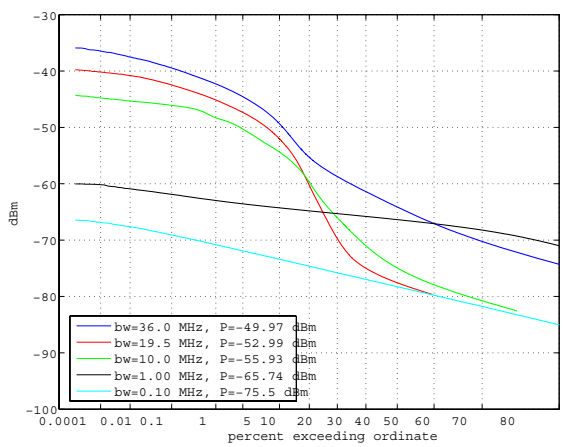

Figure 2. Amplitude statistics of MB-OFDM that hops between three bands and dwells at each band for a single MB-OFDM word (312.5 nanoseconds).

Figure 3. Test set-up (photograph by F.H. Sanders).

Proponents of DS-UWB and MB-OFDM both seek standardization from IEEE 802.15 working group 3a on high-rate (greater than 20 million bits per second) wireless personal area networks (WPAN). As the name implies, WPAN is intended for short-distance (<10 meters) wireless networking of portable and mobile computing devices, e.g., PCs, personal digital assistants, digital cameras, mobile phones, and other consumer electronics. The standards process has reached a stalemate. At the heart of the issue lie fundamental questions regarding the interference UWB devices impose on legacy victim receivers.

This study was intended to address UWB interference issues and provide scientific answers to the following questions: (1) Which type of modulation, DS-UWB or MB-OFDM, causes the most performance degradation to victim receivers? (2) Do existing FCC compliance metrics and measurement procedures adequately predict performance degradation due to UWB interference? To get at these questions ITS focused on a single victim receiver, C-band satellite digital television.

C-band satellite television receivers provide an excellent victim receiver to be tested for UWB interference susceptibility because: (1) the operational frequency band (3.7–4.2 GHz) lies within the band allocated for UWB emissions; (2) signals transmitted by satellites are weak at Earth stations, making them vulnerable to interference; and (3) satellite television broadcast technologies cover a broad range of communications techniques (analog and digital) and signal processing concepts (modulation, multiplexing, error correction, interleaving, encryption) allowing for a number of operational scenarios to be investigated.

In this study, ITS attempted to identify measurable interference metrics that correlate with performance degradation in C-band satellite receivers. Toward this end, we developed procedures for characterization of signals representative of existing and proposed UWB systems. Additionally, we designed a conducted experiment comprised of a satellite signal simulator, interference generation by a Vector Signal Generator, and performance monitoring of the victim receiver via an MPEG transport stream monitor.

Additional information may be found at: www.its.bldrdoc.gov/home/programs/uwb_interference/.

Recent Contribution

IEEE 802.15.3a standards contribution, “Estimating and Graphing the Amplitude Probability Distribution Function of Complex-Baseband Signals,” by R. Achatz, M. Cotton, and R. Dalke.

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NOAA Weather Radio Performance Study

Outputs

- VHF receiver and transmitter measurements and testing.
- FSK simulation.
- Baseband waveform analysis.

The National Weather Service (NWS) tasked ITS to examine the NOAA Weather Radio (NWR) system from signal generation to signal reception. NWR broadcasts round-the-clock weather information to all U.S. states, coastal waters, and protectorates. The NWR network consists of over 900 FM transmitters operating at 100, 300, and 1000 watts. Each transmitter uses one of seven evenly-spaced frequencies between 162.400 and 162.550 MHz, with a bandwidth of 25 kHz. In addition to the familiar audio weather forecasts, NWR can provide a digital alert signal consisting of a two-tone frequency shift key (FSK) 521 symbol-per-second waveform. The symbols follow the NWR Specific Area Message Encoding (SAME) protocol system. An alert uses one of over 75 SAME event codes and numerous location codes to warn the public of natural and man-made hazards. There are four levels of alerts in increasing significance: statements, emergencies, watches, and warnings. Messages range from a High Wind Warning to more recently added events such as a 911 telephone outage emergency. As part of its mandate to be an all-hazards network, NWR also has been chosen to carry public notices of terrorist attacks and changes in the color-coded national threat level.

ITS conducted a series of receiver measurements that were based on tests outlined in the recent Consumer Electronics Association standard entitled "Receiver Performance Specification for Public Alert Receivers" (CEA-2009) which describes the proposed performance requirements of NWR receivers. These receivers are not only capable of decoding weather related SAME massages, but are also able to decode messages associated with the new mandate to make NWR an all-hazards public alert network. ITS performed CEA-2009 tests on a wide range of NWR receivers to ascertain their performance. Additionally, ITS devised a number of measurements not in the specification. This work will be used to determine baseline operational parameters (e.g., sensitivity and out-of-band rejection) for off-the-shelf NWR receivers and future NWR receivers as they are brought to the market. This information will aid the NWS in maintaining and developing enhancements to the NWR network.

A series of tools were developed during the course of this project, including software to simulate SAME waveforms, Audio FSK (AFSK) modulator and demodulation routines, and other tools to create waveforms to stress NWR receivers. Figure 1 shows output from one of the performance tests that made use of the ITS-developed SAME simulation tools. In this experiment, simulated NWR transmissions were made at frequencies at and near 162.425 MHz in order to determine the receiver's reception bandwidth.

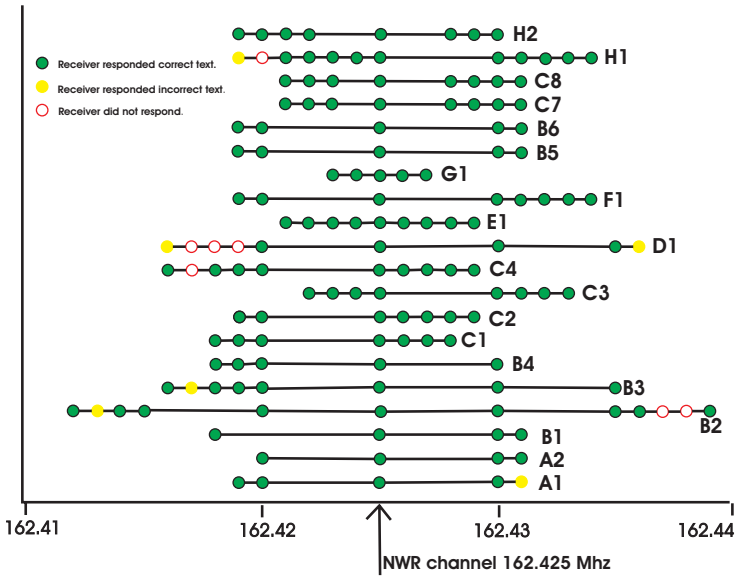

Figure 1. Output from receiver performance test. A black-bordered green circle indicates that the receiver responded at that frequency with text matching the event broadcast. A full yellow circle means the receiver responded with text other than that for the event broadcast. A red-edged empty circle means the receiver did not respond at that frequency.

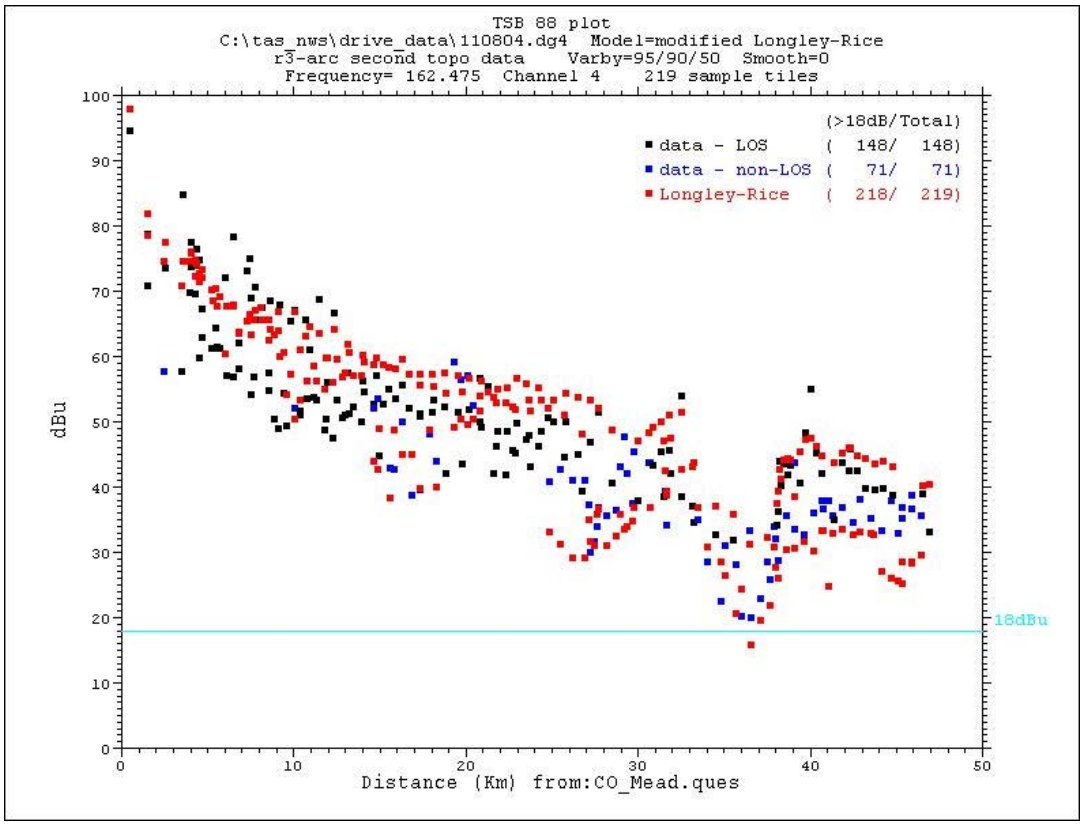

Figure 2. Scatter diagram output from drive test. The model-generated field strength estimate for each tile appears as a red dot. The black and blue dots are data points. These data points are different colors to differentiate between line of sight (LOS) locations and non-LOS, as determined by the terrain profile.

The study also identified measurement techniques that can be used to maintain and evaluate NWR transmitters at a high performance level. The general recommendations outlined in the study allow the NWS to conduct coverage and signal quality tests. The ITS transmitter measurement system was mounted in an automobile and driven through the area of interest. One of the most interesting outputs from the data collection and analysis software developed from this project can be seen in Figure 2. The scatter diagram is used to determine if the coverage criteria for a NWR transmitter has been satisfactorily met. Each dot represents a 1 km^2 tile in the coverage area. For each tile the drive test passed through, there may have been several subsamples taken. Each subsample was collected in such a way as to mitigate the effects of Rayleigh fading. Each subsampled tile was then compared to the ITS propagation model output from ITS's Telecommunications Analysis (TA) Services (pp. 36-37) and against prescribed performance criteria. In this case that minimum performance dictates that the field strength must be greater than 18 dBµV.

In the course of this work, interoperability of the baseband SAME encoders was examined in some detail. These are the devices that generate SAME messages at the command of local NWS offices. These devices are divided into two classes; those governed by NWS specification and those under FCC control as part of the Emergency Alert System (EAS). An effort was made to characterize these devices by examining such parameters as frequency stability, symbol time statistics and interface performance.

This is only a small sampling of the performance measurements and outputs that were conducted to evaluate the NWR system. ITS plays a pivotal role in evaluating the NWR network and other communications systems that are vital to the general public.

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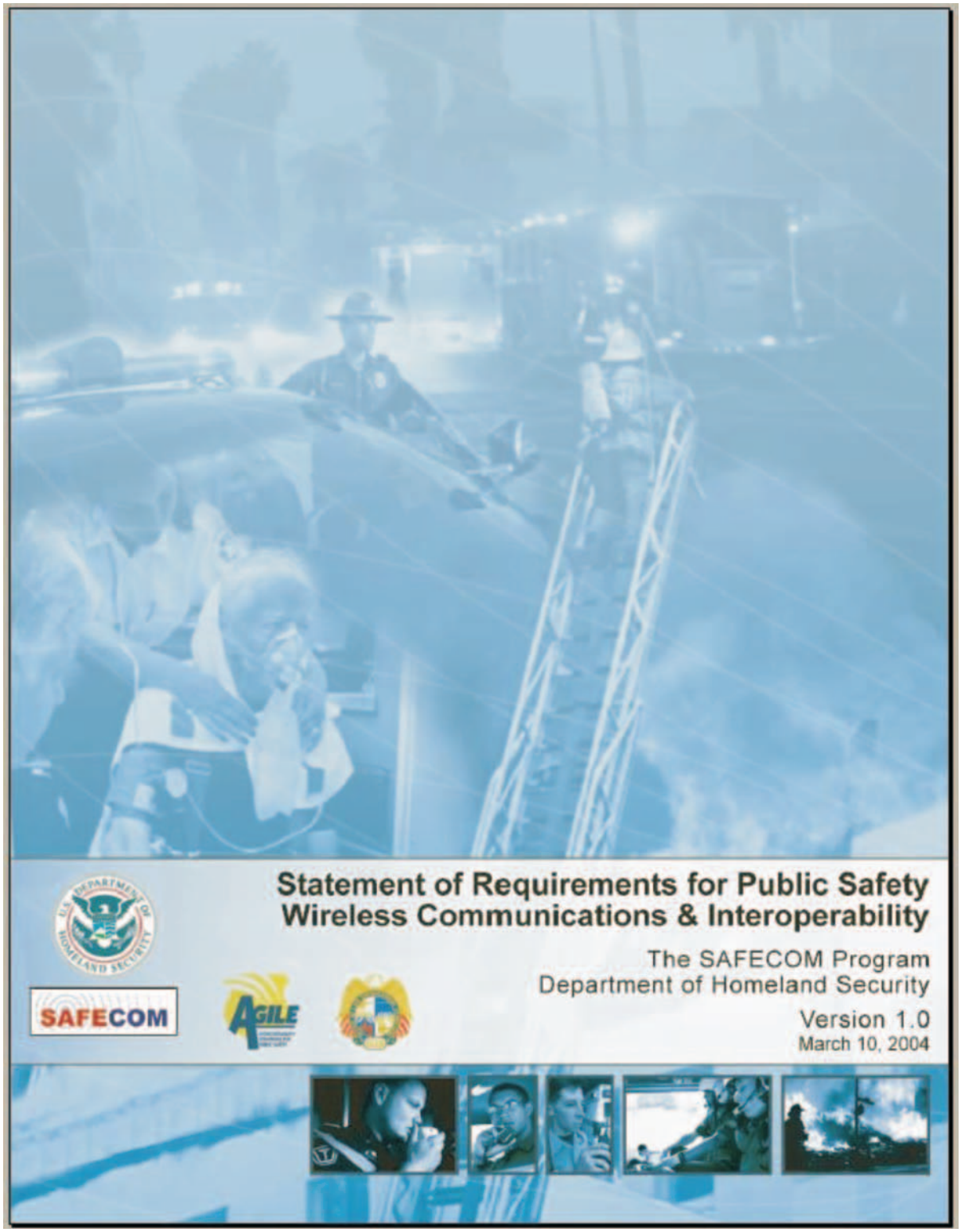

The following language by the U.S. Congress was included in the Conference Report on H.R. 4818, Consolidated Appropriations Act, 2005: "The conferees commend the Institute for Telecommunication Sciences (ITS) in Boulder, Colorado, for all their efforts and contributions to the public safety communications statement of requirements. Their contributions were critical in addressing the many issues plaguing public safety organizations for decades."

Telecommunications and Information Technology Planning

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

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

Following is a summary of significant activities that occurred in the area of telecommunications and information technology planning during FY 04. By far, telecommunications interoperability was the largest program area.

Areas of Emphasis

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

Engineering Support and Coordination.

Information Technology Interoperability Standardization and Quality.

Wireless Telecommunications Interoperability Standardization.

Emergency Telecommunications Service (ETS)
The Institute develops and verifies ETS Recommendations for ITU-T Study Group 9. A second project provides ETS expertise relating to Network Survivability for Technical Subcommittee T1A1. These projects are funded by the National Communications System (NCS).

Networking Technology/Interoperability
The Institute characterizes and analyzes the fundamental aspects of networks, and network interoperability. Methodologies and tools are developed to address discovery, monitoring/measurement, simulation, management, security/protection, and quality issues. This project is funded by NTIA.

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

Outputs

- Technical evaluations of industry R&D and community grant proposals.
- Interoperability and performance evaluations of Project 25 equipment.

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

Standards Support

Through research conducted in its Interoperability Research Laboratory (IRL), ITS tendered key contributions to standards development organizations supporting justice, public safety, and homeland security goals. In cooperation with NTIA's Office of Spectrum Management, the IRL catalogued the receiver selectivity of a cross section of Land Mobile Radios (LMRs) operating in a variety of simulated environments employing different modulations and conflicting channel plans. The underlying data were used to validate a new radio receiver selectivity model proposed in the draft of TIA Technical Service Bulletin (TSB)-88, Rev. B. Results of Project 25 Radiofrequency Subsystem throughput delay measurements performed on base stations provided a much needed context for anticipated throughput delays in the extended Inter-RF Subsystems Interface (ISSI) currently being specified in the Project 25/Telecommunications Industry Association (TIA) TR-8 committee. IRL engineers are currently reconstructing the Delivered Audio Quality (DAQ) test methodology referenced in TSB-88-B. Effective use of DAQ as a system quality metric for LMR coverage testing has been hampered by the absence of documented, repeatable test methods. The DAQ definition project will provide clear and concise instructions on how to perform such measurements. The published results will be backed by a publicly available, exhaustive compendium of thousands of audio recordings of impaired RF channels.

R&D Support

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

Test and Evaluation

The IRL has been equipped to support a broad variety of testing requirements, especially public safety applications. Testing continues along three radio-centric thrusts: receiver and transmitter performance measurements, interoperability of the common air interface, and evaluation of the effect of interconnect or network impairments. Leveraging the core

automated testing capabilities developed last year, IRL engineers expanded the lab's repertoire of performance tests well beyond the initial suite of Co/Adjacent-Channel Rejection measurements to include several additional tests defined in the TIA-102 suite of standards. Interoperability testing of subscriber units continued with more than 3000 test conditions and dozens of documented functional failures having been observed to date. This first stage of testing illustrated several common functional discrepancies in the subscriber units and motivated more efficient testing methods for future work. Accordingly, IRL engineers continue to lay the groundwork for automated testing through the creation of a standard P25 Superframe generation program capable of simulating nearly every combination of channel parameters in the overhead data. IRL engineers completed an extensive analysis of the effect of latency, jitter, and packet loss on a Project 25 repeater employing a new proprietary Voice over IP (VoIP) protocol. In addition to exhaustively characterizing this device, lessons learned in the course of testing promise to lay the foundation for similar measurements on the aforementioned P25 ISSI. Finally, IRL engineers' core competencies were brought to bear for subscriber radio and infrastructure testing in support of the State of Wyoming's Wyolink radio communications system.

Equipment in the new ITS screen room (photograph by E. Nelson).

Technical Coordination

In FY 2004 ITS entered into a cooperative research and development agreement with the State of Wyoming's Wyolink project team to assist in the proposal, evaluation, and performance testing phases of a multi-year, statewide, VHF trunked LMR system. Practical experience gained in this effort will be applied to the development of Request for Proposal templates which public safety agencies at all levels of government can use to simplify the procurement process and ensure the integrity of the performance confirmation process.

Other Support

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

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

Outputs

- XML Data Model and Data Dictionary.
- Acoustic coupling facility for public safety audio quality testing.

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

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

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

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

XML Data Model and Data Element Dictionary Development

In prior years, ITS played a significant role in providing technical assistance and coordination in the initial development of an Extensible Markup Language (XML) Data Element Dictionary that can provide common "words" for a common "language" to be used by the justice/public safety/homeland security community. In 2003, the XML development work skyrocketed, with an order of magnitude increase in the size of the data element dictionary and 2004 saw the public release of the enlarged dictionary along with an associated data model.

The development of the Global Justice XML Data Model (GJXDM) is a significant step forward in achieving information sharing interoperability among members of the justice and public safety community. It provides a foundation for the structure of a consistent data element dictionary, documents to be exchanged, and messages to be passed. The core of the data model is the XML Data Dictionary and the corresponding "Justice" namespace. Users and developers use the "words" of the Data Dictionary to build documents that represent a particular information exchange. Based on their requirements, they can import the words by reference and can extend or restrict the definitions.

The significantly-expanded data dictionary contains over 2000 elements and is expected to meet over 90% of the information sharing requirements of the justice/public safety/homeland security community. The GJXDM was initially released in February 2004 and the current released version of the dictionary is available to the public at http://it.ojp.gov/gjxdm/ .

Audio Quality Testing for Public Safety

There are several reasons for developing high-quality acoustic coupling capabilities which are not common in telecommunications laboratories to provide speech stimulus to public safety communications devices. One reason is that the electrical interfaces are non-standard and highly specific to each manufacturer and/or device model. Another is that acoustic coupling provides a means to perform calibrated laboratory emulation of the acoustic environment experienced in the field.

Head and torso simulator with public safety headset and microphone installed (photograph by D.J. Atkinson).

One of the most significant challenges that public safety practitioners face in communicating effectively is the severe nature of the environment in which they must operate. Speech quality is directly impacted by a variety of surrounding conditions that produce high noise levels, even before operationally required tools, such as sirens, are employed. These make for very challenging communication scenarios.

The Institute's acoustic coupling facility provides emulation of practitioners within these scenarios through the use of an international standard Head and Torso Simulator (HATS). The HATS provides calibrated speakers that represent an artificial mouth, and calibrated microphones that represent artificial ears. A handset positioning system allows public safety communications equipment to be positioned as it would be used in real life. The figure shows the HATS with a headset and noise canceling microphone installed.

Once the communications equipment is properly positioned, the HATS is placed into the sound-attenuated chamber where high-quality digital recordings of operating public safety equipment are played through a surround-sound system. The acoustic environment from a particular public safety event is then introduced (e.g., police car in pursuit, fire truck in route; helicopter in the air, boat involved in high-speed chase).

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

Outputs

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

Five steps are needed to specify and implement wireless systems for communications and information exchange to allow seamless interoperability among public safety agencies and practitioners: (1) define *user requirements* for communications and information exchange, (2) specify the *architecture framework* to support the communications, (3) develop *standards* for the systems, (4) conduct *technology performance tests* to evaluate proposed solutions for the standards, and (5) conduct *vendor products functional tests* to validate that tested equipment supports the standards prior to user implementation. ITS is the common technical thread through all these steps in direct support of the justice/public safety/homeland security community users to standardize their wireless systems.

ITS is conducting a technical program aimed at facilitating effective interoperability and information sharing among dissimilar wireless telecommunications systems within the justice/public safety/homeland security community. The primary focal points of the program are: (1) the identification and delineation of wireless telecommunications functional and interoperability requirements, (2) coordination with major Federal players and local, state, and tribal public safety practitioners to collegially develop an architecture framework that is in effect "a system of systems," and (3) the identification and/or development of standards that address the defined requirements and are in concert with the architecture framework. Standardization efforts are aimed at allowing local, state, tribal, and Federal agencies to exchange communications and information.

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

Wireless Telecommunications Statement of Requirements (SOR)

The first comprehensive set of wireless telecommunication requirements for public safety is now available, supplementing the PSWAC (Public Safety Wireless Advisory Committee) Final Report (1996). The development of any far-reaching nationwide strategy for wireless interoperability (and the standards to implement it) demands that practitioners' needs be clearly understood before approaches are drawn. On behalf of the public safety community, ITS took the lead in developing a contemporary SOR in 2003. The final document underwent practitioner review and was released in April 2004. The document title is *Statement of Requirements for Public Safety Wireless Communications and Interoperability – Version 1.0*, and is available at http://www.safecomprogram.gov/files/SCI_Statement_of_Requirements_v1_0.pdf. This SOR is focused on the functional needs of public safety first responders — Emergency Medical Services (EMS) personnel, fire fighters, and law enforcement officers — to communicate and share information as authorized when it is needed, where it is needed, and in a mode or form that allows the practitioners to use it effectively. The communications mode may be voice, data, image, video, or multimedia that includes multiple forms of information. To keep the emphasis on functional requirements, the SOR avoids specifying either technologies or business models (i.e., whether requirements should be addressed through owned products and systems, or via commercial services).

Wireless Communications and Information Exchange Architecture Framework

Through its sponsors, the Institute is supporting the development of an architecture framework for wireless communications and information exchange interoperability. Working with those in the Federal Government responsible for the final plan, most notably SAFECOM, ITS is expediting the overall Federal effort by taking advantage of background engineering work already conducted at the Institute and elsewhere. For example, ITS has investigated frameworks for high-level enterprise architectures, and is also reviewing and analyzing the wireless integration activities being performed, and being contemplated, by local, state, tribal, and regional governmental organizations to characterize common architectural elements that have been successfully applied in the field. Governance and other non-technical issues have also been researched. Once the architecture framework (system of systems) document matures, it will be reviewed and approved by the practitioners as was the SOR. The framework will then guide the development of standards that support it.

Two ITS engineers recording audio noise in a typical Public Safety first responder's noise environment.

Project 25/TIA TR-8 and Project MESA

The Institute contributes widely to Project 25, a program devoted to developing a comprehensive series of interoperability standards for the new generation digital land mobile radio (LMR) operating in narrowband channels for public safety applications. Comprised of representatives from the Association of Public-Safety Communications Officials (APCO) International, the National Association of State Telecommunications Directors (NASTD), industry as represented by the Telecommunications Industry Association (TIA), and local, state, tribal, and Federal governments, Project 25 is closely aligned with TIA's Standards Committee TR-8 (TR-8 is the body that formally develops, approves and releases Project 25 standards as TIA 102 series documents). While Project 25/TIA TR-8 "Phase II" work is now addressing interoperability standards for the network portions of Project 25, the specification of interface standards for (Phase I) 12.5-kHz digital LMRs also continues. "Phase III" (also referred to as Project 34 and Project MESA) is a joint effort between TIA and the European Telecommunications Standards Institute and is focused on the development of standards for broadband mobile data applications.

An ITS engineer represents NCS on the Project 25 Steering Committee, and chairs the Project 25 Encryption Task Group where Information System Security (INFOSEC) standards have been developed. ITS also contributes heavily to other TIA TR-8 committees and Project 25 task groups. For example, ITS' technical and editorial efforts have enabled the completion of initial drafts of two new TIA standards that will define Inter-RF Subsystem Interface (ISSI) measurement methods and specify recommended ISSI performance objectives. ITS continues to have the responsibility for developing procedures to test the interoperability of Project 25 radio systems. To date, procedures have been developed to test radios employing conventional voice, encrypted voice, over-the-air re-keying, trunking, and data applications.

Project MESA efforts have concentrated on defining the public safety requirements for broadband mobile applications. To date, the Institute has provided user operational requirements to Project MESA. These requirements represent the United States position. An ITS engineer was elected Chair of the Technical Specification Group — Systems. One objective of the Chair is to ensure that public safety user requirements — rather than industry solutions — are the drivers of the specifications and standards that are developed.

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Emergency Telecommunications Service (ETS)

Outputs

- Technical contributions to ANSI Working Group T1A1.2.
- Technical contributions to ITU-T Study Group 9.

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

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

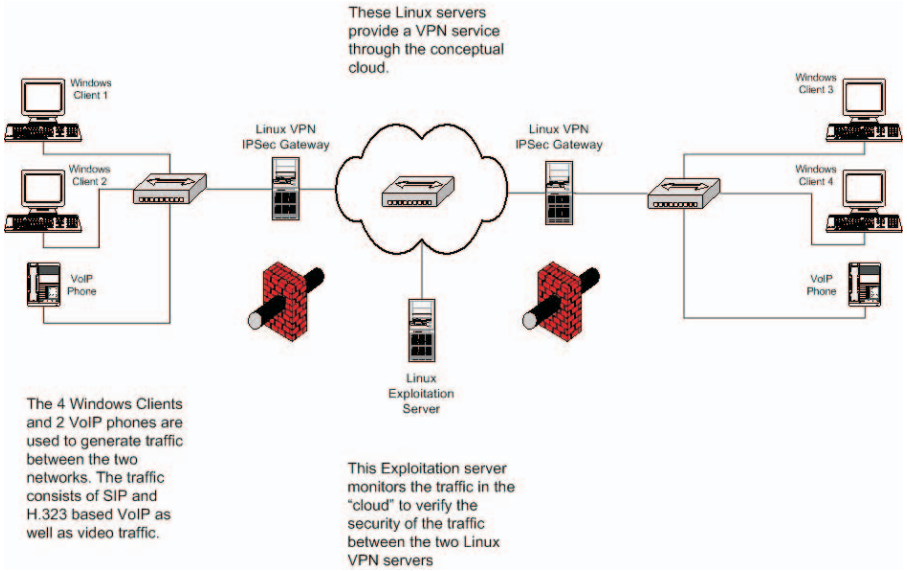
In the first project, Packet-Switched Networks, ITS develops and verifies ETS Recommendations for ITU-T Study Group 9. The major goal of this project is to ensure that future ETS mechanisms will interoperate over broadband cable television networks. Additionally, the project is working to facilitate the evolution of GETS over the IPCablecom network.

The second project, Network Survivability and Restoral, provides ETS expertise relating to network survivability and security for the ANSI-accredited Performance, Reliability, and Quality of Service Committee, PRQC (formerly T1A1). Within this project, an ITS engineer served as co-editor and principle author of a new ANSI Standard: "User Plane Security Guidelines and Requirements for ETS." This Standard provides guidelines and requirements for security aspects of ETS communications relevant to the user plane. These specifications are necessary for implementation and maintenance of secure and reliable ETS communications. Guidelines and requirements regarding cryptographic standards are provided as well.

Table A-1. Priorities for NS/EP Users

Priority Level	Responsibility	Qualifying Criteria
1	Executive Leadership and Policy Makers	Users who qualify for the Executive Leadership and Policy Makers priority will be assigned Priority 1. A limited number of PLMN technicians who are essential to restoring the PLMN networks shall also receive this highest priority treatment. Wireless carrier may assign Priority 1 to its technicians with operational responsibilities.
2	Disaster Response / Military Command and Control	Users who qualify for the Disaster Response / Military Command and Control priority will be assigned Priority 2. Individuals eligible for Priority 2 include personnel key to managing the initial response to an emergency at the local, State, regional, and Federal levels. Personnel selected for this priority should be responsible for ensuring the viability or reconstruction of the basic infrastructure in an emergency area. In addition, personnel essential to the continuity of government and national security functions (e.g., conducting international affairs and intelligence activities) are included.
3	Public Health, Safety, and Law Enforcement Command	Users who qualify for the Public Health, Safety, and Law Enforcement Command priority will be assigned Priority 3. Eligible for this priority are individuals who direct operations critical to life, property, and maintenance of law and order immediately following an event.
4	Public Services / Utilities and Public Welfare	Users who qualify for the Public Services/Utilities and Public Welfare priority will be assigned Priority 4. Eligible for this priority are those users whose responsibilities include managing public works and utility infrastructure damage assessment and restoration efforts and transportation to accomplish emergency response activities.
5	Disaster Recovery	Users who qualify for the Disaster Recovery priority will be assigned Priority 5. Eligible for this priority are those individuals responsible for managing a variety of recovery operations after the initial response has been accomplished.

The table on the previous page is taken from the Appendix of the new ANSI Standard. It defines 5 levels (1 is highest) of emergency users or priorities. The Standard goes further and offers descriptive scenarios to further clarify the distinctions. These levels will be used in the classification of ETS users regarding their security needs. An ITS engineer is now serving as editor on four new draft Standards and Technical Reports related to Security and/or ETS in PRQC's Network Reliability and Security Subcommittee (formerly T1A1.2).



Laboratory setup for testing security and ETS protocols.

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

Another important study under way at ITS is a series of tests of GETS over IPCablecom networks. The evolution of GETS from a PSTN-only service to one that will interoperate over the wireless, IPCablecom, and Next Generation networks (NGN) is one of the goals of NCS. Determining the security needs of ETS in IPCablecom networks is another goal of the ETS effort. The figure above shows a laboratory setup to test proposed ETS mechanisms over virtual private networks (VPNs) and through firewalls. The lab setup is currently used to test the performance of videoconferencing and Voice over IP over SIP. Proposed ETS mechanisms will be coded and tested over the same network to determine if they are viable from a Quality of Service (QoS) standpoint.

In FY 2005, ITS will continue to address work on the development and standardization of ETS in ATIS PRQC, the IETF, and ITU-T Study Group 9. The projects will address technologies in the NGN and interactions with the IPCablecom networks. This work on ETS must of necessity be conducted with the help of representatives from network providers and cable television equipment manufacturers, as well as NCS. The work in FY 2005 will focus on survivability and security in the NGN ETS as well as GETS compatibility in the IPCablecom networks.

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Networking Technology/Interoperability

Outputs

- Transportable equipment suite for network characterization and simulation.
- Automation for public safety audio quality testing facility.

ITS has a long history of assisting other agencies and organizations with their telecommunication planning, assessment, and interoperability studies, but the complexity of today's telecommunication and information technology (IT) requirements, and the technology available to satisfy those requirements, create demands for enhanced sophistication in the methodologies and tools used to perform these studies. The Networking Technology/ Interoperability projects have defined structured methods for such studies, examined many tools and techniques that can be used in conducting such studies, and identified those tools and methodologies most likely to provide the greatest benefits. Previous years' work focused on the selection and use of a suite of networking tools that aid in discovering the topology of a network, the load on segments of a network, and the simulation of a network, as well as the development of a structured approach to applying these tools, along with a systems engineering method to address the complex issue of network interoperability. This past year's work focused on packaging and automating tools that can be used to implement the structured approach, resulting in two significant packages that can be used by ITS projects to meet the needs of their sponsors.

Network Characterization/Simulation Suite

Essential in determining how to get to where one wants to go is knowledge of where one is starting from. This is true of many things, including network and interoperability planning. In order to provide assistance in determining the current state of a network (i.e., network characterization), ITS has developed a suite of equipment that can be used to characterize networks of significant complexity.

The suite, housed in two shock-mounted equipment racks, can be shipped to a sponsor's site to provide network monitoring and analysis over a pre-determined time interval. It provides tools to perform four stages of characterization for networks: 1) discovery and analysis, providing a big picture of the network and identifying critical components; 2) network management and monitoring based on Simple Network Management Protocol (SNMP) for aggregate link analysis and determination of problem areas; 3) protocol analysis and application-specific monitoring for isolation of specific issues; and 4) simulation that can be used to re-create the network as-is and overlay new services and components to ensure any changes will meet the user's requirements. This high level process is shown in Figure 1.

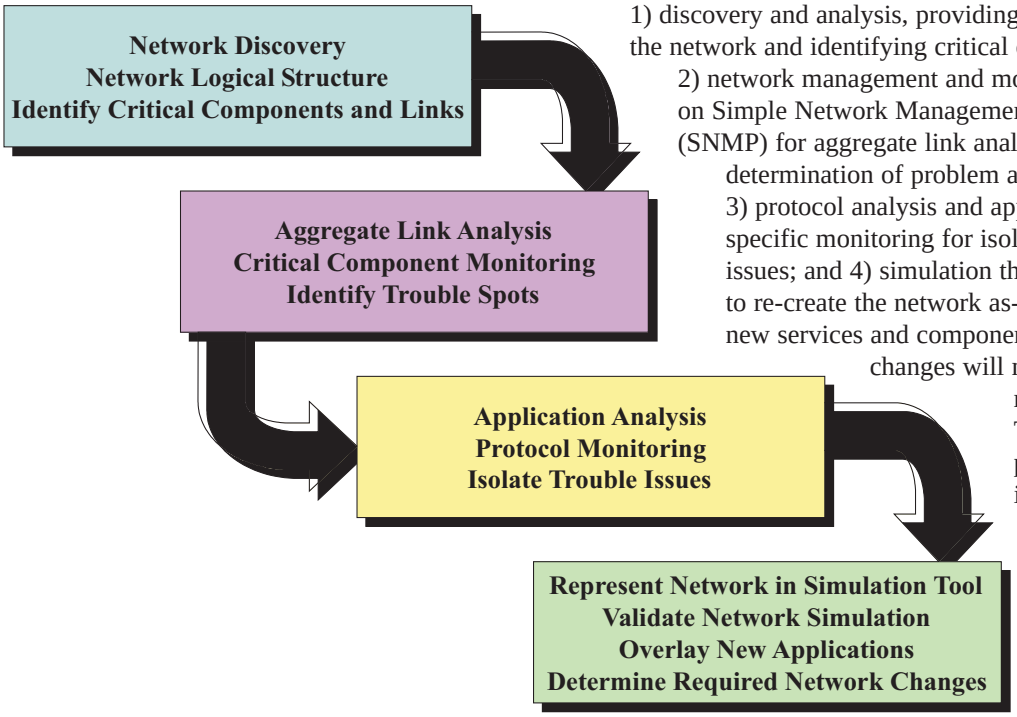

Figure 1. Network characterization process.

Figure 2. Public safety audio quality laboratory (photograph by D.J. Atkinson).

Public Safety Audio Quality Laboratory Automation

Determining the audio quality level that is required by public safety is complicated by several factors. Mixing different disciplines, environments, equipment types, frequency bands, and technologies greatly increases the number of communications variables for the public safety community. All of these factors need to be considered when it comes time to test a piece of communications equipment to determine if it provides adequate quality to the end user of the system. Further, these tests must be both accurate and repeatable.

In order to achieve this, and to support the Public Safety efforts within the division, this NTIA-sponsored program provided support to automate the public safety audio quality laboratory. The base of the audio laboratory is provided by two sound-attenuated chambers with full surround-sound capability to enable the emulation of the noise environments encountered by public safety practitioners. The sound mixing and distribution systems utilize 48 kHz digital audio (higher than CD quality) to ensure the fidelity of the testing, and the software-controlled digital mixing and recording system ensures that tests are reproducible. This is shown in Figure 2. The public safety practitioners are represented by International Telecommunication Union (ITU) standardized Head and Torso Simulators (HATS). The HATS systems provide calibrated speakers to represent the mouth and calibrated microphones to represent the ears.

This project provided automation software to ensure tests conducted in the facility are accurate and reproducible, including calibration, level setting, and automated speech processing. Accurate calibration is essential when using acoustic coupling to a communications device, so the calibration feature allows the audio path to be accurately regulated (to within ± 0.2 dB). The ability to set and recall configuration and level settings for the mixer ensures that the audio path is unchanging from test to test. Finally, the analysis feature either allows digital recording of the output from the communications device for later analysis or will do immediate processing with the ITU-approved Perceptual Evaluation of Speech Quality (PESQ) objective audio quality measurement algorithm.

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Telecommunications Engineering, Analysis, and Modeling Division engineers staffing the ITS booth at MILCOM 2004 in Monterey, California (photograph by T. Riley).

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 includes assessment of the components of telecommunications systems; evaluation of protocol and transport mechanism effects on network survivability and performance; and assessment of the impact of access, interoperability, timing, and synchronization on system effectiveness in national security/emergency preparedness (NS/EP), military, and commercial environments.

Analysis is often performed in association with Telecommunications Analysis (TA) Services, which offers analysis tools online via the Internet. In addition, ITS can provide custom tools and analyses for larger projects or specialized applications.

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

Our wireless test facilities and research capabilities allow ITS engineers to examine 2.5G and 3G technologies in detail. The Wireless Networks Research Center (WNRC) in combination with the 802.11 outdoor testbed can accommodate studies of emerging technologies and PCS, analysis of wireless protocols, and studies of wireless network effects, e.g., congestion, and capabilities, e.g., priority access. (See page 69 for information about the WNRC and page 63 for information about the wireless links at Green Mountain Mesa.)

Areas of Emphasis

ENGINEERING

PCS Applications

The Institute participated in the transition from Telecommunications Industry Association (TIA) committee TR46.2 to the Alliance for Telecommunications Industry Solutions (ATIS) subcommittee G3GRA (Radio Aspects of GSM/3G and Beyond). ITS is developing PCS interference models in a project funded by NTIA.

U.S. Coast Guard Rescue 21 Technical Consulting

The Institute assists the U.S. Coast Guard in testing and evaluating its new communication capabilities by acting as a third-party technical consultant. The project is funded by the U.S. Coast Guard.

ANALYSIS

Telecommunications Analysis Services

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

Geographic Information System Applications

The Institute continues to develop a suite of Geographic Information System (GIS) based applications for propagation modeling and performance prediction studies. This work is funded by the DoD.

MODELING

Broadband Wireless Standards

The Institute develops new radio propagation algorithms and methods that improve spectrum usage of wireless systems. Technical standards are prepared that support U.S. interests in third generation (3G) broadband wireless systems. The project is funded by NTIA.

Propagation Model Development & Comparisons

The Institute compares and harmonizes existing propagation models, to improve their predictive accuracies and reduce the differences between their predictions. This project is funded by NTIA.

PCS Applications

Outputs

- Self-interference models for current and proposed PCS technologies.
- Technical contributions to an industry-developed inter-PCS interference standard for predicting, identifying, and alleviating interference related problems.

Personal Communications Services (PCS) has become an important resource for establishing emergency communication services following natural or man-made catastrophes. Such disasters can damage the wireline telecommunication system, forcing users to migrate to cellular resources. This sudden influx of traffic by private, commercial, civil, and Federal users results in wireless system overloads, a decrease in signal quality, and disruption of service in the affected area. Additional factors contribute to diminished channel capacity of a wireless network, such as co- and adjacent-channel interference and the operation of multiple, independent, non-interoperable systems servicing the same geographical area, often using the same frequency bands and infrastructure (base station sites and towers). National security/emergency preparedness (NS/EP) planners and network operators must understand these interference effects to operate effectively in an overloaded environment.

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

ITS has contributed to the understanding of inter-PCS interference by participating in the Telecommunication Industry Association (TIA) committee TR46.2 (Mobile & Personal Communications 1800-Network Interfaces). As a member of TR46.2, ITS contributed to the development of the Technical Service Bulletin "Licensed Band PCS Interference" (TSB-84A). This bulletin is a first step in characterizing the interfering environment caused by large numbers of active users and competing technologies. Since the completion of TR46.2's work, coverage of PCS interference concerns has been transferred to the Alliance for Telecommunications Industry Solutions (ATIS) subcommittee G3GRA (Radio Aspects of GSM/3G and Beyond), formerly T1P1.2. ITS continues to be involved in interference issues with this new group.

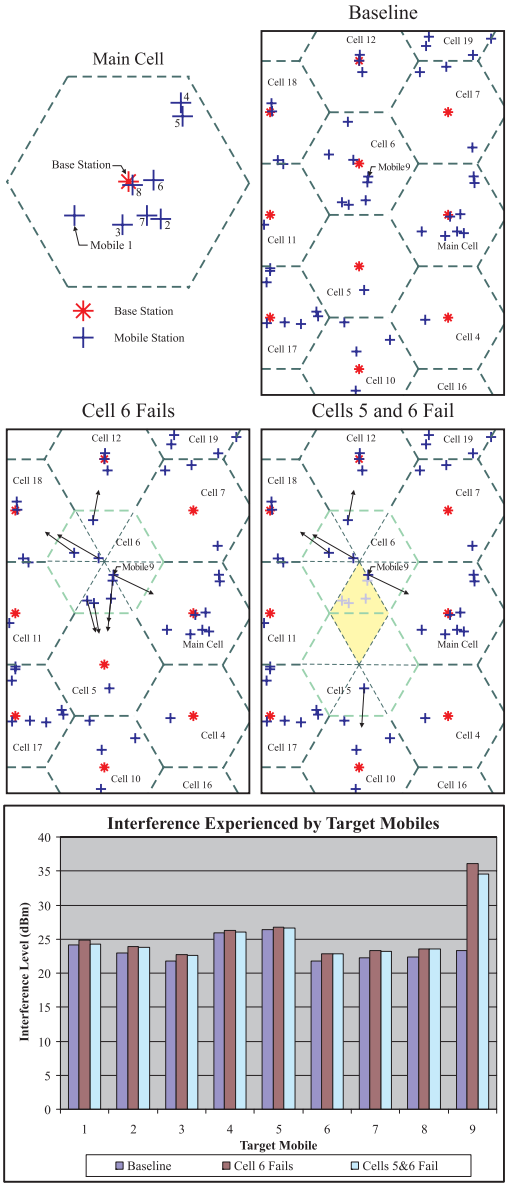
Detecting, identifying, and mitigating co-channel interference requires tools to characterize the interference experienced by PCS air-interface signals. PCS interference models are tools used to predict levels of interference and identify sources of interference. Several standard propagation models are accepted by industry members (i.e., Okumura and COST-231/Walfish/Ikegami) but no interference models have been developed or accepted. ITS is developing a series of PCS interference models starting with a model based on the ANSI/TIA/EIA-95-B standard, and leading to models covering proposed third generation (3G) systems. The model covers system-specific interference modeling to determine co-channel interference from both immediate and adjacent cells. It is based on the 95-B standard which produces a representation of an instantaneous 95-B air interface signal. The signal can contain outputs of multiple base stations with variable numbers of channels for each base station and can assign relative power levels for each individual channel. Both forward and reverse link processes are included in the model.

The input for the model is a sequence of binary values. This sequence can be random, but has no requirement to be random. For forward link signals, the appropriate Walsh code and orthogonal I and Q short pn codes spread the input sequence. For reverse link signals, the model modulates the input sequence with Walsh codes

and then spreads the sequence with long and short pn codes. The resulting I and Q data streams pass through a baseband filter and a quadrature phase shift keyed (QPSK) or an offset QPSK (OQPSK) modulation scheme. The model calculates each channel signal contribution separately and then adds the processed signal to the other signal contributions to form a composite output signal. The power level for a single channel is an arbitrary gain factor of the baseband filter which is set separately for each channel. All the Walsh and pn code definitions come from requirements in the 95-B standard. The output of the model consists of a vector of numerical values representing a sampled QPSK or OQPSK signal. There is no error correction added to the input sequence, only spreading codes and modulation processes are used. This model does not check for recovery information contained in the input. Its only purpose is to determine how well the system can transmit the bits of the input binary sequence.

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

The figure displays a typical scenario showing the effects of system failure on the co-channel interference experienced by mobile stations in a cellular system. All cells in the system are populated by a single, centrally located base station, and a variable number of mobile stations which are randomly positioned within the cell. The main (center) cell contains eight mobiles, numbered as shown. Cell 6 contains eight mobiles, while cell 5 contains a single mobile. In the baseline state, all base stations are operating and are servicing their respective mobile stations. When the base station of cell 6 is removed, the mobiles of cell 6 are picked up by their nearest base station. In this situation, the main cell's base station picks up a single mobile (mobile 9), cell 5's base station picks up four mobiles, and the remainder are picked up by other surrounding cells. The plot shows the increase in co-channel interference experienced by the eight mobiles in the main cell, as well as mobile 9 whose service is transferred to the main cell. When the base station of cell 5 is removed, an assumption is made that the four mobiles that cell 5 picked up from cell 6 (those located in the yellow, diamond-shaped area) are no longer in position to receive service from any adjacent cell's base station. They are removed from service and no longer affect the interference levels of nearby mobiles. Cell 5's single mobile is picked up by its adjacent cell, and the interference levels for the nine mobiles being observed are recalculated. The plot shows the resultant change in interference. In most cases, interference is reduced due to the loss of the four mobiles that lost service. Mobiles 6 and 8 show almost no change in experienced interference due to their proximity to the main cell's base station.



Typical system load analysis scenario utilizing ITS' PCS co-channel interference model.

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or Teresa L. Rusyn, (303) 497-3411 e-mail trusyn@its.bldrdoc.gov

U.S. Coast Guard Rescue 21 Technical Consulting

Outputs

- Written technical feedback on design and test documents.
- Radio Frequency (RF) analysis.
- Witnessing of field and factory tests on location.
- Meeting attendance as subject matter experts.

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

ITS has an Interagency Agreement with the Coast Guard to provide technical expertise during the Developmental Testing and Evaluation (DT&E) phase of Rescue 21. DT&E includes two levels of testing — a Formal Qualification Test (FQT) at the contractor's facility, and a System Integration Test (SIT) in the field. ITS provided technical consulting to the Coast Guard for the entire DT&E phase. For both FQT and SIT, written analysis and recommendations were provided on the test approach, test plans, and test procedures. ITS also participated in the witnessing of both tests on site.

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

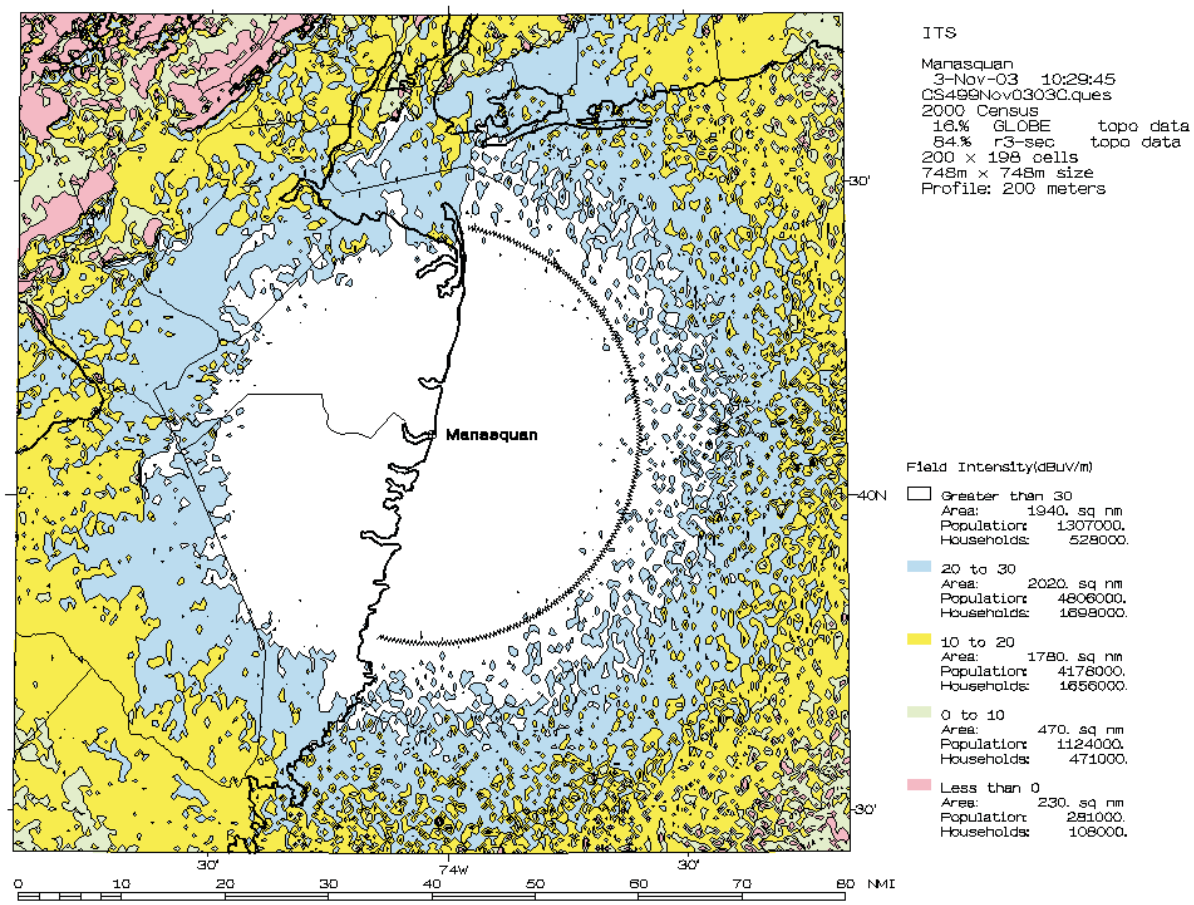
Performance Availability
All GCC's in the system are networked together with the rest of the Coast Guard communications functions, and must have the capacity to track Coast Guard assets and emergency calls as they are passed from region to region. ITS provided analysis of the effect of network traffic on system availability.

RF Coverage
The Rescue 21 system is required to provide RF coverage along the entire U.S. coastline, lakes, and intercoastal waterways, out to a 20 nautical mile boundary. ITS reviewed the SIT test plans to ensure that the test procedures would result in a reasonable proof of the coverage requirement. Measurement methods and sampling paths and locations were analyzed for compliance with TSB-88 and standard practice for communication coverage testing.

Propagation Modeling
In support of the RF coverage analysis, ITS provided the Coast Guard with antenna coverage predictions using the Irregular Terrain Model (ITM) and the Advanced Propagation Model (APM). These models were used to anticipate the effects of ocean wave heights on the coverage area (see the figure on the next page).

Voice Quality
ITS is a recognized expert in the area of Voice Quality analysis, and provided written recommendations to the Coast Guard for analyzing the voice quality received over Rescue 21 wireless channels against the specifications in the system requirements.

Direction Finding
The new system will be able to create a line of bearing in the direction of vessels in distress within one degree of accuracy. ITS used its experience with direction finding systems in the analysis of test plans and procedures.



Effect of 10m waves on propagation coverage area (area shown is the New Jersey shoreline).

P25 Specifications and Requirements

The Rescue 21 Performance Specification requires interoperability with other emergency response agencies through utilization of P25 equipment. ITS applied its expertise in this area to the review of test documents for parts of the system which use P25.

RF Interference

One key factor in RF coverage is the consideration of the RF noise environment. ITS analyzed test plans and procedures to ensure proper measurement of the RF environment and the expected effects on RF coverage. In addition, one of the upgrades Rescue 21 provides to the Coast Guard over its current communications system is the capability for simultaneously communicating over multiple channels. ITS provided technical input in the area of intermodulation interference during simultaneous communications.

As Rescue 21 nears the end of DT&E, ITS continues to provide technical feedback and analysis on the test data and results, helping the Coast Guard verify whether or not the system specifications and technical requirements have been met.

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Telecommunications Analysis Services

Outputs

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

Telecommunications Analysis Services (TA Services) gives industry and Government agencies access to the latest ITS research and engineering on a cost reimbursable basis. It uses a series of computer programs designed for 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.

Currently available are: on-line terrain data with 1-arc-second (30 m) 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; Federal Communications Commission (FCC) databases; and geographic information systems (GIS) databases (ARCINFO). For more information on available programs, see the Tools and Facilities section (pp. 68–69) or call the contact listed below.

TA Services is currently assisting broadcast television providers with their transition to digital television (DTV) by providing a model for use in advanced television analysis (high-definition television, advanced television, and digital television). This model allows the user to create scenarios of desired and undesired station mixes. The model maintains a catalog of television stations and advanced television stations, updated weekly from the FCC, from which these scenarios are made. Results of analyses show those areas of new interference and the population and number of

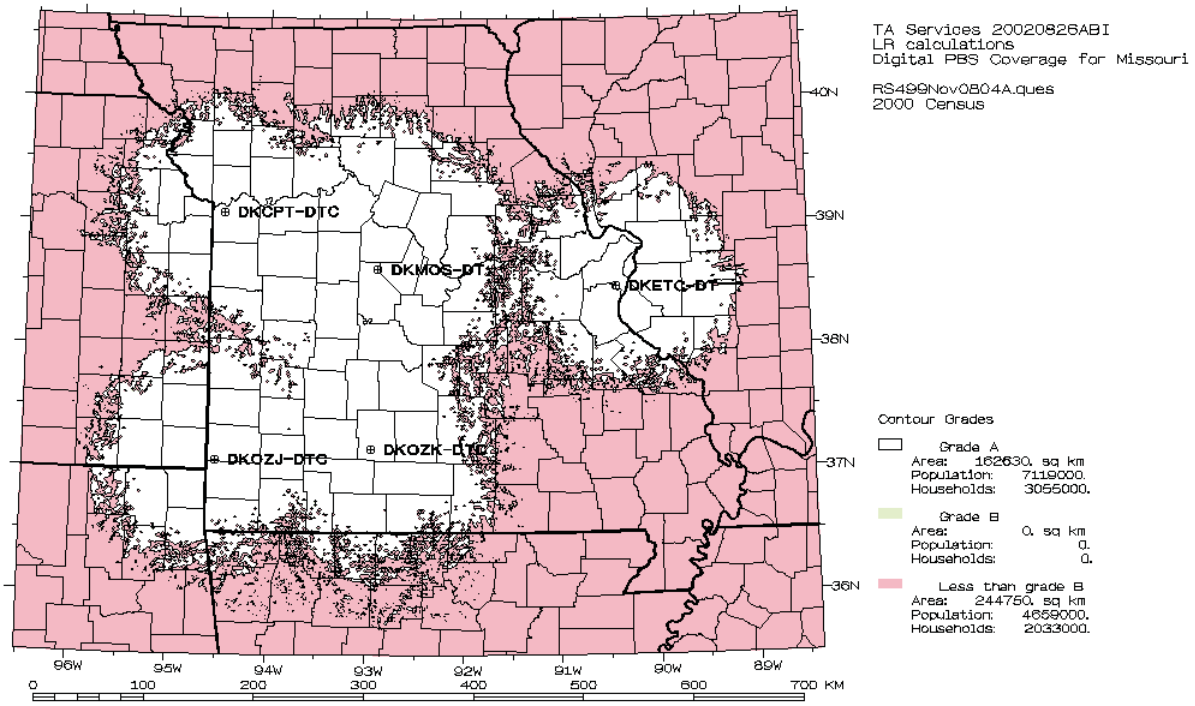

Figure 1. Digital PBS TV coverage for Missouri.

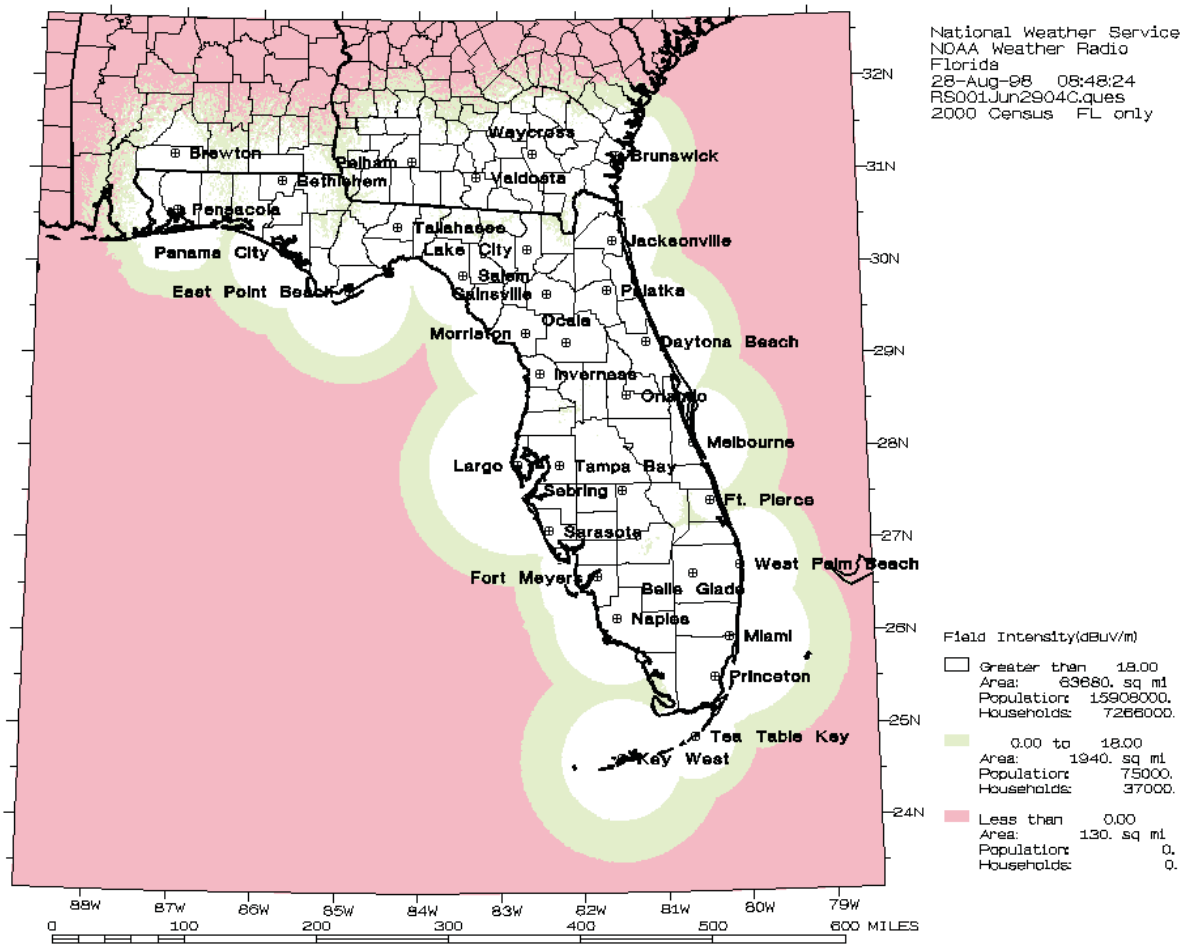

Figure 2. NWS station coverage for Florida.

households within those areas. The model can also determine the amount of interference a selected station gives to other stations. This allows the engineer to make modifications to the station and then determine the effect those modifications have on the interference that station gives other surrounding stations. In addition to creating graphical plots, the program creates tabular output which shows the distance and bearing from the selected station to each potential interferer as well as a breakdown of the amount of interference each station generates. This year, using this same program, all of the Public Broadcasting Service's (PBS) digital TV stations (350) were converted to ArcView shape files and sent to PBS for use with their own GIS software. Figure 1 on the previous page shows the digital PBS TV coverage for Missouri.

TA Services is also assisting the National Weather Service (NWS) in locating additional sites to increase its coverage for weather radio reports and emergency warning broadcasts, such as those issued in September 2004 for hurricanes on the east coast. Figure 2 above shows the calculated NWS coverage for Florida. TA Services calculates that 99.5% of the Florida population should be able to hear NWS weather radio broadcasts.

All models in TA Services and their outputs can be accessed via a network browser at http://flattop.its.bldrdoc.gov.

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Geographic Information System Applications

Outputs

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

Figure 1. An analysis area created for the city of Boston.

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

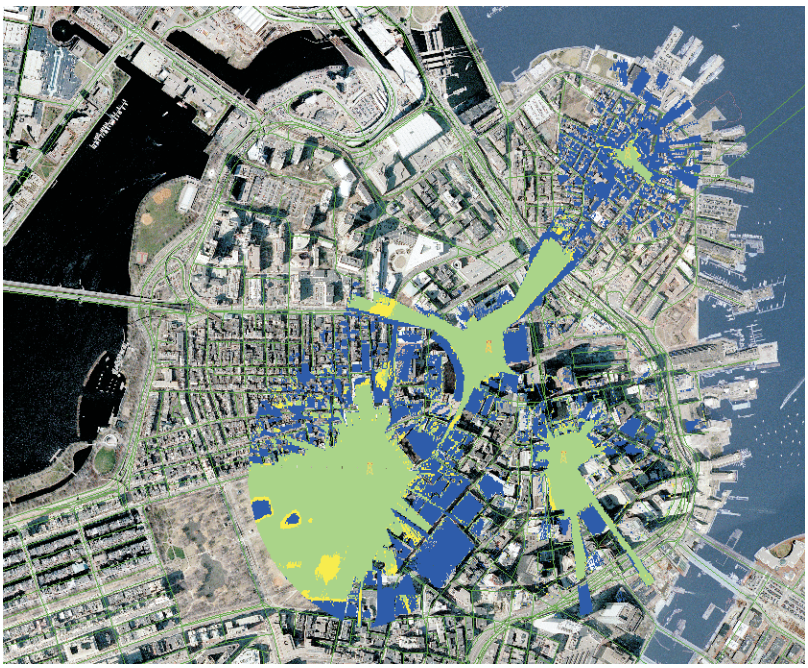

Figure 2. A composite coverage of four transmitters.

One GIS based tool developed by ITS is the Communication Systems Planning Tool (CSPT). CSPT is a menu and icon driven propagation model developed for frequencies from 20 MHz to 20 GHz that allows the user to connect to a variety of image catalogs and terrain libraries that cover most of the world. The user can create specific analysis areas using these catalogs and libraries and can then perform propagation

scenarios for his/her application. These applications can range from outdoor coverage studies of large-scale areas of hundreds of square miles to indoor propagation studies of one building in an urban environment.

Figure 3. Signal to interference analysis with red indicating significant interference.

Current work efforts involve the development of standalone and web-based GIS tools for outdoor and indoor propagation modeling as well as visualization capabilities that allow the user to fly into the analysis area and move around the environment as the tool updates the visualization imagery to the resolution appropriate to the display environment. The user can then drape coverages of outdoor and/or indoor scenarios and move around the environment to examine the output.

The general flow of the CSPT GIS Tool is as follows. The user defines an area within which a study will be performed. This analysis area can be defined graphically by zooming into a map of the world or of the U.S. or by defining the latitude and longitude of the boundaries of the desired area. The user then imports desired GIS information such as political boundaries, roads, rivers, special imagery, or application-specific GIS data. Figure 1 shows an analysis area created for the city of Boston.

After creating the analysis area, the user creates or imports transmitter, receiver, and antenna data. Lastly, the user selects the type of coverage and the propagation model to be used in the analysis. Figure 2 shows a composite analysis of the coverage of four transmitters located throughout the city. The analysis can be limited to sectors and specified distances around each transmitter to speed up calculations and focus on an area of interest.

Interference analyses can be run allowing the user to specify the signal to interference contours and colors as shown in Figure 3.

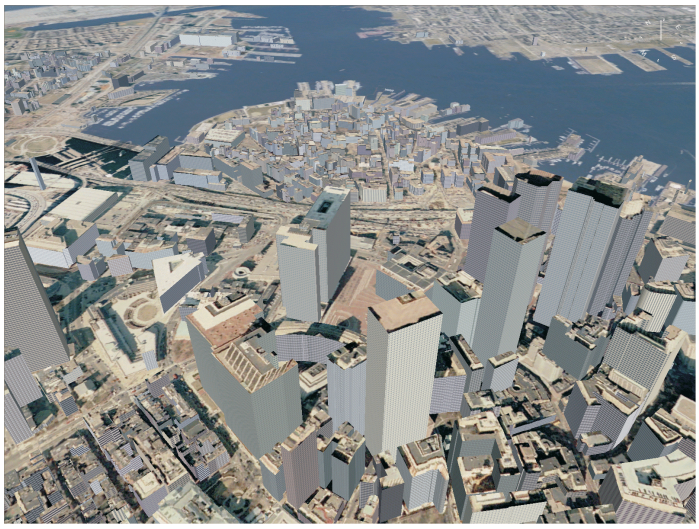

Figure 4. A 3D visualization of the city of Boston.

Coverages, composites and interference analyses can be imported into visualization tools allowing the user to see and often fly through their studies so that a better understanding of the analysis results can be obtained. Figure 4 shows a 3D visualization of the Boston skyline made by such a visualization tool. Many such tools exist and ITS is developing methods to export CSPT coverages into such visualization tools.

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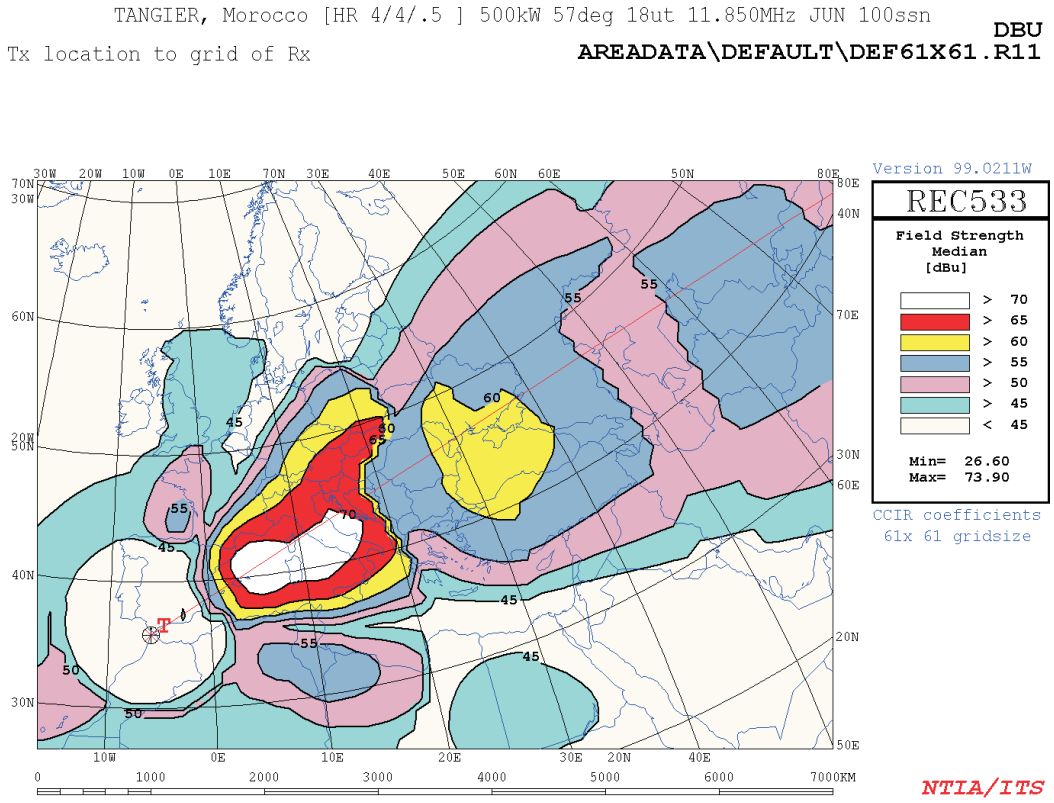
Broadband Wireless Standards

Outputs

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

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

Historically, radio propagation model development tended to be very service specific, with models for the broadcast FM radio and television service or for the land mobile radio service and little or no overlap in applicability between the models for different services. This service specific approach was adequate for a regulatory philosophy that assigned different, exclusive blocks of the radio spectrum to different services in a proprietary fashion. However, this lack of overlap between models can also create an impediment to the shared use of spectrum by different services or wireless applications, because, for example, a model that is used to predict intra-service system availability and interference might not also apply flexibly and accurately to inter-service interference predictions. To overcome this problem, ITS



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

and other research organizations have been developing and evaluating propagation models to predict wireless signal coverage more accurately and flexibly, both within and across services.

The ITS Irregular Terrain Model (ITM) is one such general purpose model for the prediction of radio propagation over tropospheric circuits, in the frequency range 20 MHz – 20 GHz. This model may be used for radio propagation predictions in its area (i.e., site-general) mode, when little, if any, detailed information is available for the path. It may also be used for radio propagation predictions in its point-to-point (i.e., site-specific) mode, when detailed terrain elevation data are available for the path. For either mode, the model first generates the predicted reference attenuation (i.e., the computed median attenuation in excess of free space) as a function of distance, based on three ranges, corresponding to the dominant radio propagation mechanisms in these ranges: line-of-sight, diffraction and tropospheric scatter. This computed reference attenuation is then modified by the desired quantiles of the time, location and situation variabilities, combined as necessary to give reliability and confidence estimates.

ITS participates in the international development of radio propagation prediction models that can be used by spectrum managers and system planners of land mobile, terrestrial broadcast, maritime mobile and certain applicable fixed (e.g., point-to-multipoint) services, among others. ITS supports this effort by participation in the International Telecommunication Union — Radiocommunication Sector (ITU-R) Study Group 3 (Radiowave Propagation). Study Group 3 recently developed and adopted a radio propagation model which blends features that the different services had previously used independently, thereby clarifying and unifying planning and coordination activities across these services. This recommendation, Recommendation ITU-R P.1546, is usually considered to be a site-general model, although, for improved accuracy, it specifies numerous adjustments and corrections to the basic method that are very nearly site-specific in their application. In preparation for the recently-held first session of the Regional Radio Conference (RRC-04) and to support the work of the Intersessional Planning Group (IPG) established by the RRC-04,[1] Study Group 3, Working Party 3K (WP 3K, point-to-area propagation) and, in particular, Subgroup 3K-2 have undertaken a number of significant revisions of Recommendation ITU-R P.1546. For several years, an ITS engineer has served as chairman of Subgroup 3K-2.

As a much needed adjunct to this work, Subgroup 3K-1 of WP 3K and Study Group 3 is examining and evaluating proposals for the use of several different site-specific radio propagation models that are broadly applicable and flexible for intra- and inter-service planning and coordination uses, when detailed terrain elevation data are available. ITS, in cooperation with U.S. Study Group 3, has submitted two U.S. contributions to WP 3K proposing the ITM (point-to-point mode) and a closely related hybrid radio propagation model, based on Recommendations ITU-R P.1546 and P.452. The performance of these models will be thoroughly evaluated in the upcoming year with the results of these studies provided to WP 3K through further U.S. contributions.

In addition to the above areas, WP 3K deals with propagation aspects of short-path personal communications and wireless local area networks (WLAN) in the frequency range 300 MHz to 100 GHz, and wireless access systems in these frequency ranges. Time permitting, recently obtained propagation data for dense and moderate urban and suburban environments will be submitted as additional U.S. contributions to WP 3K.

ITS also participates in the work of Working Parties 3J (propagation fundamentals), 3M (point-to-point propagation, earth-space propagation, interference and coordination) and 3L (ionospheric propagation). ITS continues to be responsible for the HF (3–30 MHz) propagation software developed by the ITU for international frequency coordination. The ITU website, http://www.itu.int/ITU-R/software/study-groups/rsg3/databanks/ionosph/index.html, links to an ITS web site with the following reference, HF sky-wave propagation (Rec. P.533) (available from the ITS web site) http://elbert.its.bldrdoc.gov/hf.html. An example of the type of output that the software can produce is shown in the figure on the previous page.

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

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Propagation Model Development & Comparisons

Outputs

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

Propagation model development in FY 2004 focused on improving the effective height algorithm in the ITS Irregular Terrain Model (ITM). Radio propagation predictions made using the ITM are highly influenced by the effective heights of the terminals. The effective heights are used to compute several intermediate quantities that may have a large impact on the prediction.

To estimate effective heights in the point-to-point (site-specific) mode, the ITM utilizes least squares fitting to a portion of the terrain profile, and a comprehensive path profile analysis. The portion of the profile utilized depends on whether or not the direct ray's elevation has terrain clearance. If the path is line-of-sight (LOS), the least squares fit is applied to the central 80% of the terrain elevations between the terminals, yielding a single linear function with distance, extrapolated to each terminal's endpoint to estimate its effective height. If the path is transhorizon, a least squares fit is applied to the central 80% of the terrain elevations between each terminal and its corresponding radio horizon distance. For both paths, each of the terminals' effective heights is always limited to be at least the corresponding height above ground of the radiation center.

For any given transhorizon path, polarization, and frequency of operation, the net effect of increasing the effective heights is to reduce ITM's predicted reference attenuation. The converse is also valid, but reductions in the effective heights are limited to the corresponding terminals' heights above ground. However, for any given LOS path, polarization, and frequency of operation, the possibility of constructive and destructive "interference" effects between the direct ray and the ray reflected from the ground may or may not reduce ITM's predicted reference attenuation as the terminals' effective heights increase, up to a point. Beyond that point, increasing the terminals' effective heights will lead to reductions in ITM's predicted reference attenuation.

Previous comparison studies of measured propagation data and ITM's point-to-point mode predictions have indicated that, in some cases, the algorithm tends to overestimate the terminals' effective heights. This is true of the datasets with low terminal radiation center heights above ground. However, examination of individual measurement data and predictions indicated that, for many of these, an effective height estimate greater than the radiation center height above ground improved ITM's prediction accuracy, compared to substitution of the radiation center height above ground for the effective height. Figures 1 and 2 show examples of how different the predictions can be for the two cases. In some, the effective height that improved the prediction accuracy exceeded the existing algorithm's estimate. Also found were instances where improved prediction accuracy would result if the terminals' effective heights were less than the radiation center heights above ground.

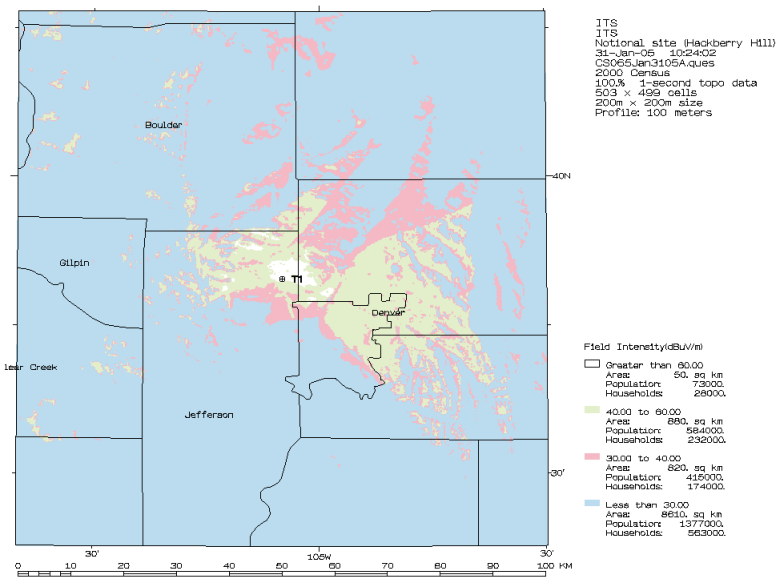

Figure 1. CSPM plot showing predicted radio coverage using ITM with the existing effective height algorithm.

The preceding discussion suggests that the effective height algorithm in ITM can be improved. However, key aspects should be retained, e.g., the subdivision of paths into LOS and transhorizon classifications, and the rule that any adjustments or limitations to the effective heights apply equally to both terminals. The latter condition is necessary to preserve reciprocity. Unfortunately, it limits the range of improvement in the prediction accuracy, because if one terminal is high while the other is low, the effective height of the low terminal is more influential on the prediction accuracy.

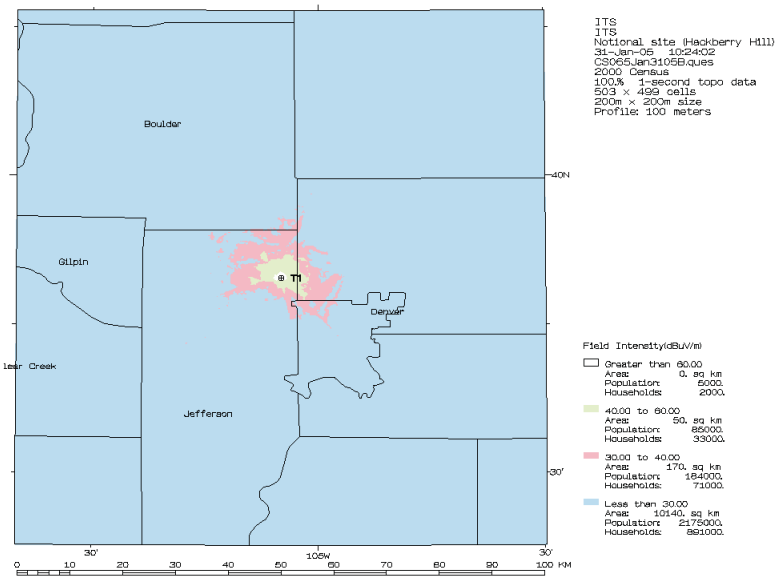

Figure 2. CSPM plot showing predicted radio coverage using ITM with effective heights set to the structural height above ground.

Two approaches to defining the terminals' effective heights have been studied thus far. Both are motivated by determining an effective ground reflection point and least squares fitting portions of the terrain profile centered on this point. The first approach was to search the terrain profile, or portion thereof, depending upon whether or not the path was LOS or transhorizon, for the point or points of reflection, based on the assumption that the terrain elevation followed a straight line with distance between any two adjacent profile points. A further condition was applied to each point detected: it must be intervisible to both terminals. We therefore label this the "glint" approach. Depending on whether no glint, one glint, or more than one glint was detected, varying portions of the terrain profile, centered on the glint or glints, were then least squares fitted and the resulting line or lines were extrapolated to the terminals' locations to estimate the effective heights. If no glint was detected, the method defaulted to the existing effective height algorithm. Unfortunately, many of the paths had no detected glint, so this approach demonstrated no or only very limited improvement.

A second approach was therefore devised that searched the terrain profile, or portions thereof, depending upon whether or not the path was LOS or transhorizon, for the point of minimum clearance for the first Fresnel zone. For LOS paths, the first Fresnel zone was referenced to the direct ray between the terminals' heights above ground. For transhorizon paths, the first Fresnel zone was referenced to the ray between the terminal's height above ground and the terrain obstacle comprising its corresponding radio horizon. We thus label this the "minimum clearance" approach. Varying sections of the terrain profile were then least squares fitted and the resulting straight line or lines extrapolated to the terminals' locations to estimate the corresponding effective heights. The results of this approach usually improved the mean prediction accuracies. Although this approach is more robust, it is also suboptimal, because the prediction accuracies' standard deviations were often increased when compared to the existing effective height algorithm. Furthermore, when compared to either the means or the standard deviations of the prediction accuracies for the effective heights set at the terminals' heights above ground, there was no improvement in the prediction accuracies' statistics.

Additional effort to improve on the existing effective height algorithm is plainly required. Limiting the terminals' effective heights may help to reduce the minimum clearance approach's prediction accuracies' (absolute values of the) means and standard deviations. However, these limits must be reciprocal for the algorithm to have wider utility and applicability.

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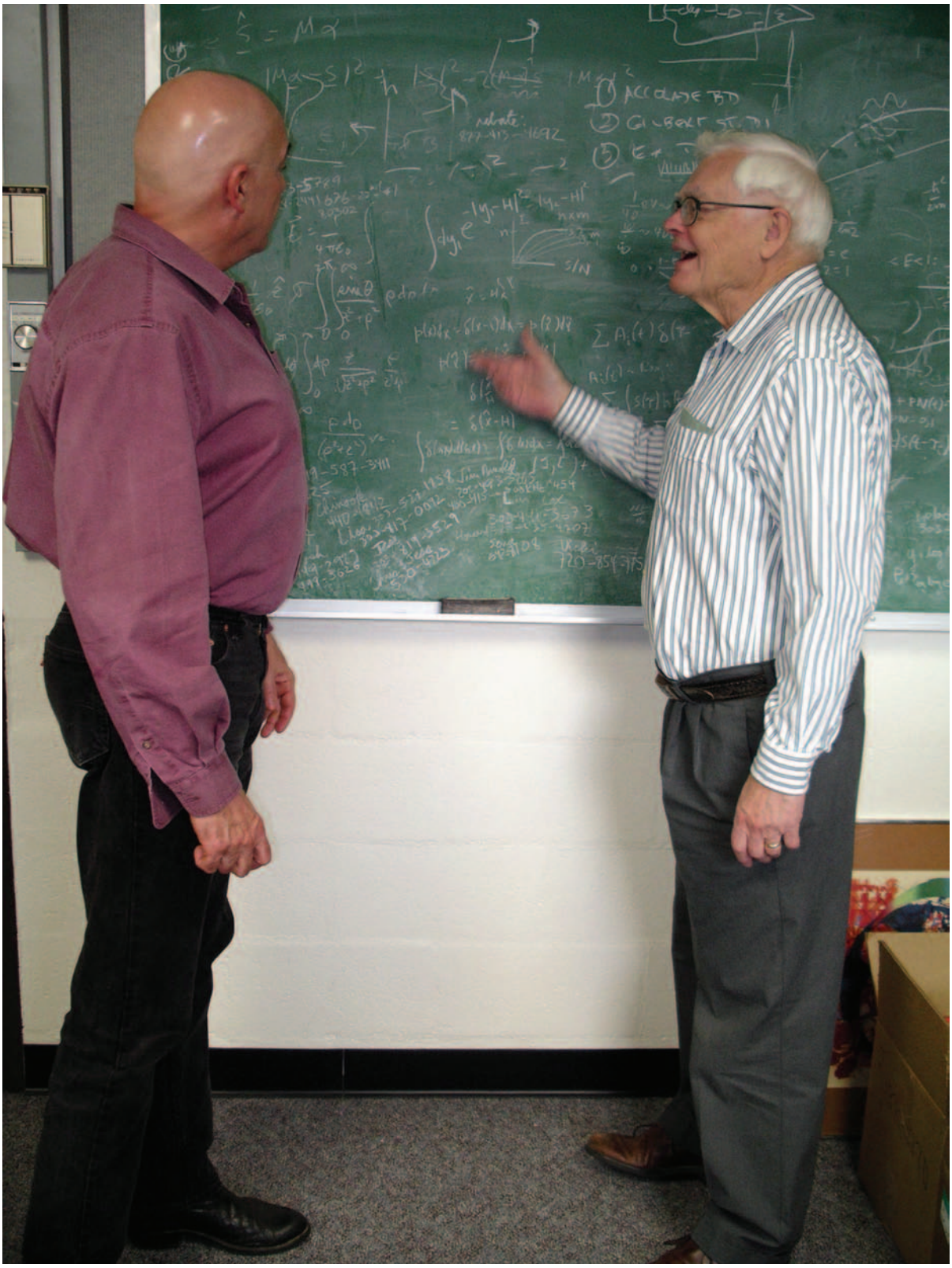

An ITS physicist and mathematician in the Telecommunications Theory Division discuss some information theory calculations regarding the channel capacity of multiple input, multiple output (MIMO) antenna systems (photograph by F.H. Sanders).

Telecommunications Theory

The rapid growth of telecommunications in the last 50 years has caused increased demand for radio spectrum and has generated high levels of loading in many telecommunications networks, both wireless and wireline. In response to these trends, new radio technologies have been developed and implemented to use spectrum more efficiently and effectively. To meet critical national needs for better radio communication systems, the parameters that limit network performance must be thoroughly understood, and such knowledge must be focused on improvements in the performance of existing and new networks. Tools to monitor the quality of audio and video information on communication channels also must be developed and used so that audio and video quality levels can be accurately adjusted in real time to achieve maximal quality with minimal use of available bandwidth.

To achieve these goals for the U.S. government as well as the private sector, the Institute's Telecommunications Theory Division performs research in both wireless and wireline telecommunications, seeking to understand and improve telecommunications at the most fundamental level. Strong ongoing investigations are maintained in the major areas of broadband wireless systems performance; advanced antenna designs; noise as a limiting factor for advanced communication systems; audio and video quality assessment; advanced spectrum sharing concepts; and radio propagation.

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

Areas of Emphasis

Audio Quality Research
The Institute conducts research and development 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.

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

Effects of Radio Channel on Networking Performance
The Institute, a recognized leader in radio channel measurement and modeling, is involved in research to assess the effects of the wireless communications channel on communications system network performance. Recent work has focused on effects of noise and interference as limiting factors in system performance. The project is funded by NTIA.

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

Audio Quality Research

Outputs

- Technical publications and presentations demonstrating new research results.
- Algorithms and data supporting speech and audio coding and quality assessment.
- Objective estimates and subjective measurements of speech and audio quality.

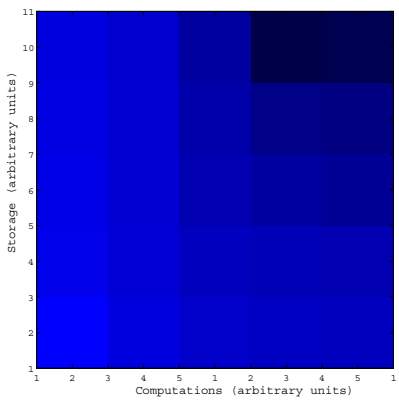

Figure 1. Bit-rate as a function of codec computations and storage. Higher rates are brighter blue.

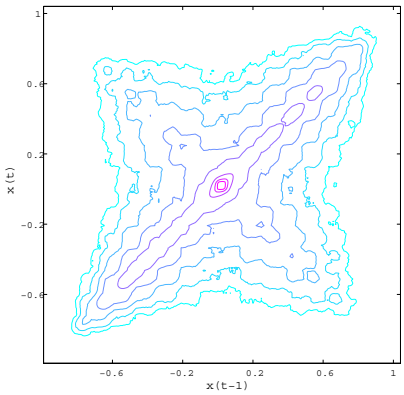

Figure 2. Contours of constant relative frequency for two-dimensional histogram of adjacent speech samples.

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

In digital coding and transmission there is a four-way trade-off among quality, bit-rate, delay, and complexity. The ITS Audio Quality Research Program works to identify and develop new techniques to increase quality or lower the bit-rate, delay, or complexity of digital speech and audio coding and transmission. The ultimate result of such advances is better sounding, more reliable, more efficient telecommunications and broadcasting services.

In one FY 2004 Program effort, a family of speech coders with fixed speech quality and fixed delay was developed. For this family, the four-way trade-off described above becomes a 2-way trade-off: complexity vs. bit-rate. Complexity is comprised of two major factors: a computational requirement and a storage requirement. Figure 1 shows how bit-rate can be reduced by increasing either computations or storage. For a given implementation, one would select the member of this speech coder family that gives the lowest bit rate and has computation and storage requirements consistent with the implementation platform.

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

One MDC approach recently developed in the Program exploits the naturally occurring correlations between adjacent samples of speech. This correlation can be seen in the way probability mass is organized along the diagonals in the two-dimensional histogram in Figure 2. Working with these correlations, one can effectively decompose a stream of speech samples into two streams that provide maximum fidelity both individually and when combined.

In digital speech and audio systems, a set of complex time-varying interactions among signal content, source coding, channel coding, and channel conditions often make it difficult to define or measure speech or audio quality. The Audio Quality Research Program operates a subjective testing facility and runs controlled experiments to gather listeners' opinions of the speech or audio quality of various coding and transmission systems. The Program has also developed and verified tools for the objective estimation of telephone bandwidth speech quality.

In FY 2004 the tools for objective estimation were further enhanced through the development, optimization, and testing of a robust technique for tracking variable transmission delay for a wide range of speech coding conditions. This is important because transmission delay can vary significantly and rapidly in packetized speech transmission systems, even within a single spoken phrase. This delay variation arises from the basic nature of packetized data networks and can be mitigated, but not eliminated, through buffering techniques. To understand the resulting speech quality, it is imperative that this continually changing delay be accurately tracked.

VoIP is presently the most prominent example of a packetized speech transmission system, but some land-mobile radio systems are also now interconnected through packetized links. Thus the Program developed a tool that is effective across the range of VoIP conditions and land-mobile radio conditions. This was accomplished through detailed analysis of a broad database that includes over 6000 different recordings. This analysis led to a successive refinement approach that can respond appropriately to each of the different conditions of interest. Figure 3 provides an example of actual and estimated delay histories for a worst-case condition involving 2.45 kbps speech coding and a high rate of packet impairments.

Signal content plays an important role in speech quality and thus the type and amount of background noise that is combined with speech can have a significant effect on speech quality. As cellular phones have become ubiquitous, they are routinely used in locations with significant background noise. In FY 2004 Program staff developed a database of digital recordings of background noise signals. This database includes recordings from bus and car interiors, office, coffee shop, and party environments, and urban sidewalk environments as well. The recordings are used in the Program to create realistic and diverse environments for speech quality assessment.

Throughout FY 2004, subjective and objective audio quality testing was conducted to support Audio Quality Research efforts. In addition, Program staff continued with selective upgrades to the ITS Audio-Visual Laboratories to keep them abreast of the state-of-the-art. Program staff continued to transfer technologies to industry, Government, and academia throughout FY 2004, using technical publications and lectures, laboratory demonstrations, and by completing peer reviews for technical journals and workshops. Program publications and other results are available at http://www.its.bldrdoc.gov/audio.

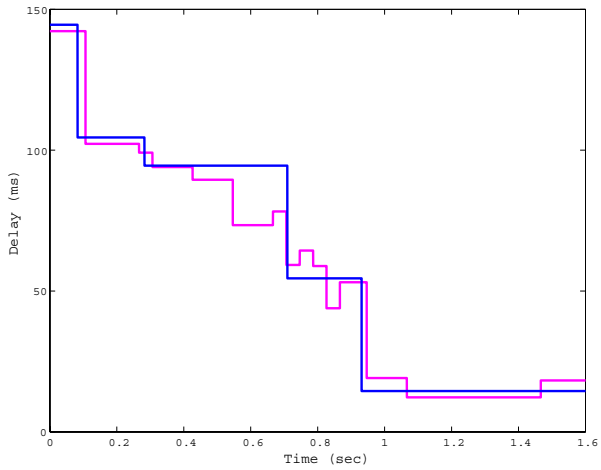

Figure 3. Actual (blue) and estimated (magenta) delay histories for 2.45 kbps speech codec with highly impaired packetized transmission.

Recent Publications

S.D. Voran, "Compensating for gain in objective quality estimation algorithms," in *Proc. International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, Montreal, May 2004.

S.D. Voran, "A bottom-up algorithm for estimating time-varying delays in coded speech," in *Proc. 3th International Conference on Measurement of Speech and Audio Quality in Networks (MESAQIN)*, Prague, Czech Republic, May 2004.

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Broadband Radio Research and Propagation Measurements

Outputs

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

An ongoing program of radiowave propagation research and measurements is supported using the ITS Mobile Measurements Facility and the Digital Sampling Channel Probe (DSCP). By using these facilities, researchers have the ability to determine propagation conditions and impairments which affect new digital communication systems and answer questions regarding the viability of proposed radio services. In the recent past these facilities were used to investigate propagation for personal communications services (PCS) at 1.85 GHz and local multipoint distribution services (LMDS) near 30 GHz. The measurement van is capable of fixed or mobile operation and the DSCP can be configured over a wide range of bandwidths and frequencies.

Recently the system was configured at four frequencies to study the relative propagation impairments between the 2.4 GHz ISM band and the recently allocated 5.8 GHz communications band. Mobile data was collected in an urban environment and the relative impairments were quantified. This data is intended to help system designers of next generation systems in the 5.8 GHz band determine the relative power requirements and link budgets needed versus systems in PCS and cellular bands. It will help promote commercial high frequency spectrum use and frequency extension. Figure 1 shows the routes surveyed in downtown Denver. Figure 2 shows the average path loss slopes over the measured frequency range. For more details of this work see references [1] and [2].

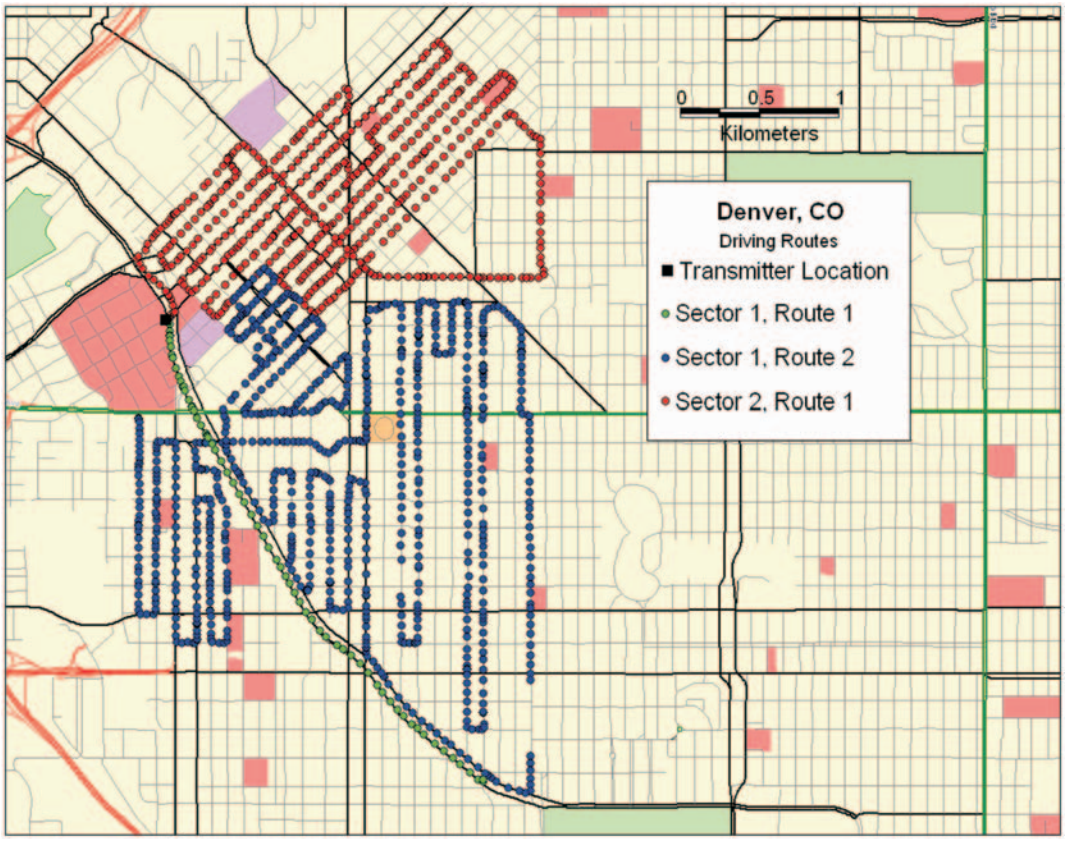

Figure 1. Drive route map for radiowave propagation survey in downtown Denver, CO.

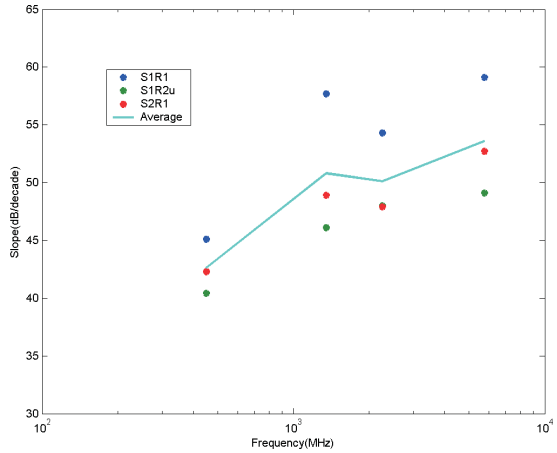

Figure 2. Lb slope versus frequency for three urban drive routes in Denver, CO.

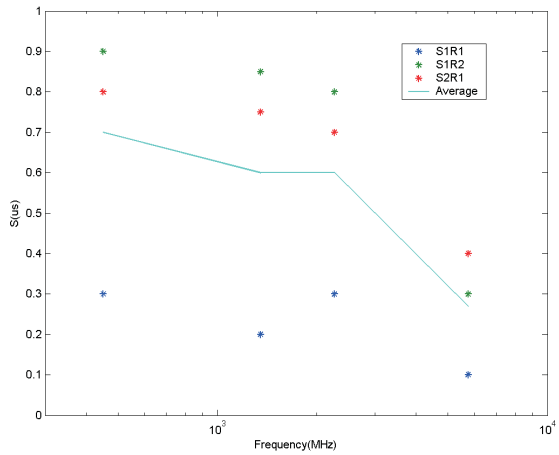

Figure 3. Average results for delay spread exceeded 50% of the time (S 50%) for 3 cells versus transmission frequency.

In addition to the path loss data, the relative delay spread versus frequency was also measured. In Figures 3 and 4 we see that delay spread decreased versus transmission frequency. More detailed analysis of these effects can be found in references [1] and [2].

In the coming year the Broadband Radio project will continue its work in the area of multiple input multiple output (MIMO) antenna systems. The purpose of this work is to advance spectrum efficiency using new high capacity radio technology. The project plans to work cooperatively with NIST to characterize a reverberation chamber for use in testing MIMO systems. ITS will also continue its study of information theory relating to MIMO systems.

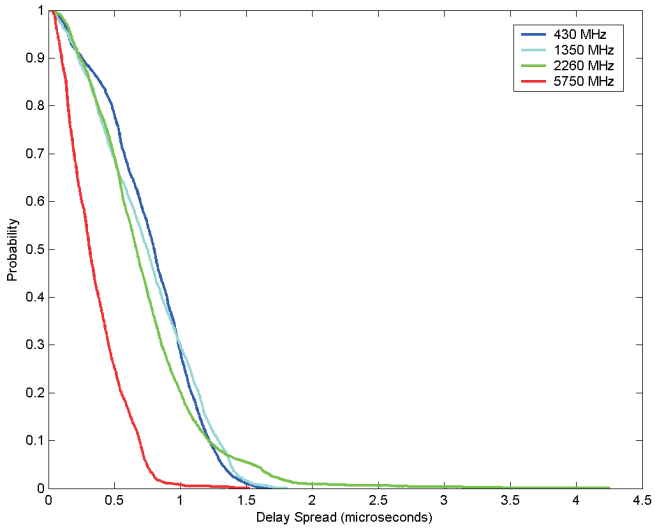

Figure 4. The cumulative distribution function of delay spread versus transmission frequency for cell 2 route 1.

Recent Publications

[1] P. Papazian and M. Cotton, "Relative propagation impairments between 430 MHz and 5750 MHz for mobile communication systems in urban environments," NTIA Report TR-04-407, Dec. 2003.

[2] P. Papazian, "Basic transmission loss and delay spread measurements for frequencies between 430 MHz and 5750 MHz," to be published in *IEEE Transactions on Antennas and Propagation*, Feb. 2005.

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Effects of Radio Channel on Networking Performance

Outputs

- Models of bit, frame, and packet error random processes.
- Quantitative analysis of effects of radio channel on network performance.
- Estimation of the radio channel's impact on spectral capacity.

The Institute is a recognized leader in radio channel measurement, modeling, and analysis. In the past 10 years this leadership has included work in characterizing multipath in personal communication services (PCS) and wireless local area network (WLAN) frequency bands as well as man-made noise at VHF and UHF frequencies. Such knowledge is essential for the development of robust mobile radio links. For example, development of new adaptive equalizers for modern, wide-bandwidth mobile radio links would not be possible without radio channel multipath measurement, modeling, and analysis.

Wireless network hosts that access the Internet are proliferating. IEEE 802.11 "WiFi" WLAN and 2.5/3rd generation PCS general packet radio service (GPRS) are but two examples. Recent research has shown that the radio channel can significantly degrade network performance by decreasing throughput, increasing delay, and losing packets. This degradation ultimately limits the usefulness of allocated spectrum.

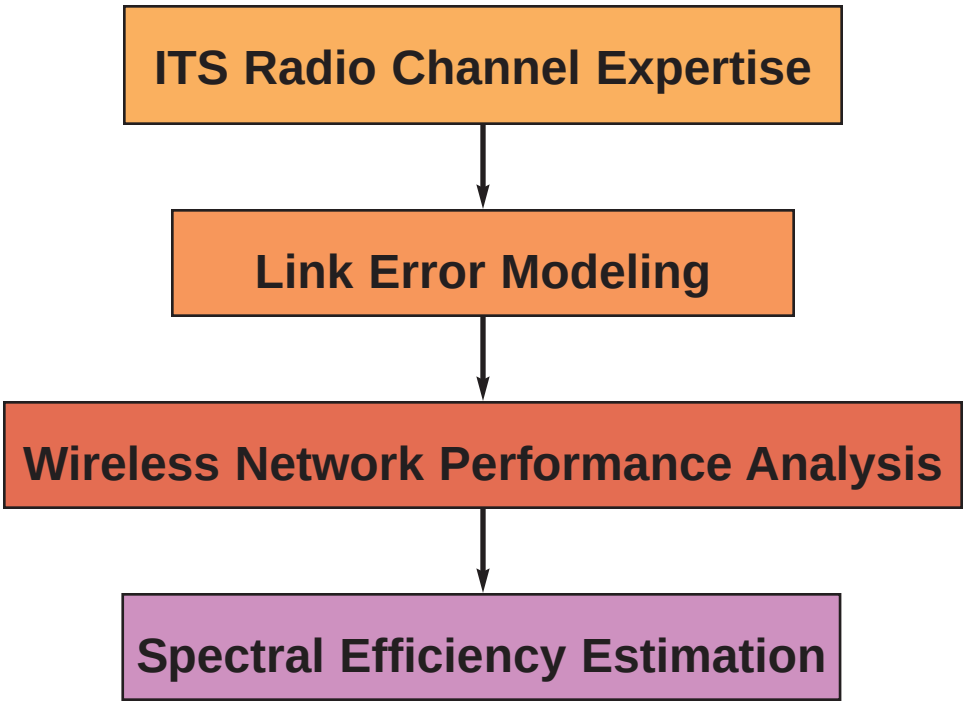
ITS is currently striving to translate its radio channel expertise into information that helps designers to improve the reliability and regulators to estimate the spectral efficiency of wireless networks. This is being accomplished by focusing on three tasks — (1) accurate modeling of the radio link bit, frame, and packet error processes resulting from radio channel impairments, (2) investigation of analytic techniques that correlate network performance to these error processes, and (3) computation of wireless network spectral capacities that account for these error processes.

Previous work included development of a radio link simulator incorporating multipath radio channel impairments. In FY 2004, this simulator was used to model bit and frame error processes caused by radio channel multipath. Initially, two frequency selective multipath radio channels were investigated. The first radio channel, referred to as the Hufford channel, had a direct path in addition to diffuse multipath created by a number of paths with independent Rayleigh fading processes. The second radio channel, referred to as the Gaussian wide sense stationary uncorrelated scattering (GWSSUS) channel, had only diffuse multipath. Bit and frame error processes due to the Hufford channel had independent, geometrically distributed time intervals. The error process due to the GWSSUS channel was markedly different.

In order to understand these differences we turned the investigation towards the analysis of the Rayleigh fading channel. Previous research has shown that the amplitudes of the Rayleigh fading channel can be modeled as a first-order Markov process where the current amplitude is dependent only on the amplitude of the previous sample. We hypothesized that the differences between the error processes may be due to the memory introduced by the first order Markov process.

We began our research by investigating the claim that the amplitude process was a first-order Markov process. The results of this investigation, currently in IEEE review, clearly demonstrated that only a fraction of the information needed to predict the current amplitude is in the previous sample and a more complex model is required to include information in earlier samples. In FY 2005, ITS plans to investigate the impact of this finding on bit and frame error processes used in network analysis and simulation.

In FY 2003, ITS completed a comprehensive search of professional literature which defined the scope of the effects of the radio channel on network tasks. This search indicated that queuing, routing, and end-to-end transmission tasks were the most severely compromised by the effects of the radio channel.



ITS is striving to translate its radio channel expertise into information that helps designers analyze performance and regulators estimate spectral efficiency of wireless networks.

Today, simulation is often used to correlate the effects of the radio channel on the performance of these tasks. However, our search also pointed out that validation of simulation results, either through experimentation or theoretical analysis, is difficult and not commonly done.

In FY 2005, we will explore new methods for validating wireless network performance simulations. One approach to this problem is to find ways of incorporating the effects of the link error process into theoretical expressions which are commonly used to predict wired network throughput and delay. These analytic expressions include Burke's theorem which is commonly used to investigate the behavior of two queues, or Jackson's theorem which is commonly used to investigate the behavior of a group of queues.

Spectrum capacity is often measured in terms of the number of voice channels which can be supported per unit area. With the proliferation of the Internet, it will become important to measure spectrum capacity in terms of the number of end-to-end packet transmission circuits the spectrum can support. This estimate will clearly be dependent on the effects of the radio channel on network tasks such as queuing, routing, and end-to-end transmission. In FY 2005, the impact radio channel impairments have on computing the spectrum capacity of packet transmission circuits will be investigated.

Recent Publication

R. Dalke and G. Hufford, "Analysis of the Markov character of a general Rayleigh fading channel," submitted to *IEEE Transactions on Vehicular Technology*.

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Video Quality Research

Outputs

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

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

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

During FY 2004, international standardization of the ITS General video quality metric (VQM) was completed with the publication of ITU-R Recommendation BT.1683 and ITU-T Recommendation J.144R. These new international recommendations provide end-users and service providers with standardized methods for measuring the video quality of standard definition television (SDTV) systems. One hundred and seventy-two new Cooperative Research and Development Agreements (CRADAs) were implemented with U.S. companies/individuals and 91 new Evaluation License Agreements (EVAs) were implemented with foreign companies/individuals. These CRADAs and EVAs provide companies with an easy mechanism for evaluating ITS video quality measurement technology and software before signing commercial licensing agreements.

During FY 2004, ITS worked to extend the above patented and standardized video quality measurement techniques to two new areas; high-definition

Figure 1. HDTV subjective viewing room.

TV (HDTV) and multimedia (MM) systems. HDTV and MM differ from SDTV in image resolution, viewing distances, display type, and user expectations. The differences between SDTV and HDTV/MM necessitate the creation of new subjective and objective testing facilities and procedures. Figure 1 shows a new HDTV subjective viewing room that was used to conduct ITS's first HDTV subjective quality experiment. Figure 2 shows a new HDTV transmission/reception system that was used to generate transmission impairments for this HDTV experiment. Viewer ratings of HDTV compression and transmission quality will be used to see if ITS's SDTV technology scales to HDTV (HDTV has approximately 4 times the resolution of SDTV). Similar investigations are being performed for MM resolution systems, which typically have only 1/4 to 1/16 the resolution of SDTV.

Figure 2. HDTV transmission/reception system.

The current VQM software for the CRADAs and EVAs mentioned above is limited to bench testing, where video from the source and destination ends of a video system under test must be present at a single PC. Work began in FY 2004 to expand the existing VQM software tools to include new end-to-end video quality monitoring capabilities. This new software tool runs on two PCs, one located at the source end and the other located at the destination end. The two PCs communicate their reduced reference features via the Internet. Using the new software tools, users and service providers will be able to monitor their end-to-end digital video quality.

Recent Publications

M. Pinson and S. Wolf, "A new standardized method for objectively measuring video quality," *IEEE Transactions on Broadcasting*, v. 50, n. 3, pp. 312-322, Sep. 2004.

ITU-R Recommendation BT.1683, "Objective perceptual video quality measurement techniques for standard definition digital broadcast television in the presence of a full reference," approved Jun. 2004.

ITU-T Recommendation J.144R, "Objective perceptual video quality measurement techniques for digital cable television in the presence of a full reference," approved Mar. 2004.

ITU-T Recommendation J.149, "Methodological framework for specifying accuracy and cross-calibration of video quality metrics (VQM)," approved Mar. 2004.

M. Pinson and S. Wolf, "The impact of monitor resolution and type on subjective video quality testing," NTIA Technical Memorandum TM-04-412, Mar. 2004.

M.H. Brill, J. Lubin, P. Costa, S. Wolf, and J. Pearson, "Accuracy and cross-calibration of video quality metrics: New methods from ATIS/T1A1," *Signal Processing: Image Communication*, v. 19, pp 101-107, Feb. 2004.

S. Wolf, "Color correction matrix for digital still and video imaging systems," NTIA Technical Memorandum TM-04-412, Dec. 2003.

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

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Support to Private Sector Telecommunications Activities:

Cooperative Research with Industry

Outputs

- PC software (VQM) that objectively measures video quality made available on the Internet for evaluation.
- Mobile, broadband measurements of propagation in urban and suburban environments made available to Lucent Bell Laboratories for research into the performance of multiple input multiple output (MIMO) antenna systems.

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

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

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

Not only does the private sector partner benefit, but the Institute is able to undertake research in commercially important areas that it would not otherwise be able to do. Active CRADAs in FY 2004 are described below.

Lucent Technologies, Bell Laboratories, and ITS completed cooperative research to evaluate the performance of multiple input multiple output (MIMO) antenna systems for mobile wireless communications. MIMO technology promises to greatly increase spectrum capacity for wireless services including high data rate mobile services.

Motorola/Freescale, Inc., and ITS made measurements to determine the potential for interference from several ultrawideband (UWB) and other signals to existing spectrum users. Two of the UWB signals studied were being considered for the IEEE standard for Personal Area Networks. The results of this work were important inputs to the IEEE standard and the FCC's rulemaking regarding UWB.

Savi Technologies and ITS measured the mutual effects between an RF identification (RFID) system and FM amateur radio equipment in the 400-MHz band.

In FY 2004, ITS received 172 new requests for copies of ITS' Video Quality Metric (VQM) software for evaluation purposes. This software objectively measures video quality as it would be perceived by end-users of a video system. ITS's VQM, already a national standard (ANSI), was made an international standard by the International Telecommunication Union. Commercial licensing of the VQM technology is available with reasonable

ITS and Savi Technologies staff at the Table Mountain field site, preparing to measure the mutual effects between an RFID and FM amateur radio equipment in the 400-MHz band (photograph by F.H. Sanders).

and equitable terms. Two new VQM commercial licenses were issued last year.

In FY 2004, ITS had 140 active accounts with the private sector for use of its Telecommunications Analysis Services (TA Services). TA Services consists of a number of wireless databases and propagation models that can be used on a reimbursable basis.

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

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

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ITU-R Standards Activities

Outputs

- Technical support to the U.S. Administration in Working Party 8B, the Radar Correspondence Group, and Joint Rapporteurs Group 1A-1C-8B, and also in Study Group 3.
- Measurements performed to determine responsiveness of prototype dynamic frequency selection (DFS) devices to radar emissions at 5 GHz.
- Tests and measurements performed on effects of interference from communication system signals into a long-range air search radar.
- Joint ITS-OSM presentation on future X-band (9300-9500 MHz) radar development, given at a meeting of Study Group 8 in Geneva.
- Joint measurements between ITS, OSM, and the Administration of Japan on emission spectra of S-band and X-band maritime radars.

Success in worldwide telecommunication markets, as well as successful, compatible use of telecommunications technologies, is critical to the long-term success of the United States in many spheres. To achieve these goals, the U.S. Administration participates in a telecommunications standards and regulatory body, the International Telecommunication Union — Radiocommunication Sector (ITU-R), to further its objectives regarding all forms of wireless communication on a worldwide basis. ITS provides important, ongoing technical support for the U.S. Administration in ITU-R Study Groups 3 and 8 (see pp. 40-41); Working Party 8B; the Radar Correspondence Group (RCG), and Joint Rapporteur Group (JRG) 1A-1C-8B. Current areas of interest include (but are not limited to): dynamic frequency selection technology proposed for 5 GHz spectrum sharing between communication systems and radars; radar emission spectrum measurement techniques; effects on radars of interference from communication systems; and development of new X-band radar technologies.

A number of proposals have been made by non-U.S. Administrations to introduce communication systems into bands heretofore allocated for radars on a primary basis. Since the U.S. Administration has made an enormous investment in the development and deployment of military and civilian radars, it is essential that new systems proposed for spectrum sharing be shown to be electromagnetically compatible with existing and future radars. To this end, ITS engineers in FY 2004 tested the new technology, called dynamic frequency selection (DFS), for the U.S. Administration. The tests were conducted jointly by ITS, NTIA's Office of Spectrum Management (OSM), and industry. The DFS prototypes under test used RLAN technology to communicate in 5 GHz spectrum used by radars. The sharing technique requires that the DFS devices must sense radar signals and then vacate frequencies used by radars. The tests at ITS determined the extent to which prototype DFS devices accomplished this goal.

Other proposed techniques for sharing spectrum between radars and communication systems require that radar receivers sometimes operate co-channel with potentially interfering communication signals. Unfortunately, very little information has ever been gathered on the effects of interference from communication signals in radar receivers. ITS and OSM have worked together for several years to learn about these effects. As part of this effort, interference tests and measurements were performed by ITS and OSM engineers in FY 2004 on a long-range air surveillance radar at a joint FAA-NORAD site. In the course of the tests, interference signals were injected into the radar receiver while targets were observed. The effects on target detection were observed at a variety of interference levels. Targets were artificially generated for some tests, and were 'live' aircraft in other tests. The radar receiver was found to be highly sensitive and susceptible to such interference at rather low levels. The test results have been used for U.S. Contributions in WP-8B.

Additional work in ITU-R has been devoted to chairmanship of the Radar Correspondence Group by an ITS engineer, as well as ongoing support and written Contributions for JRG 1A-1C-8B on the topic of future development of radar technology in the X band (9300-9500 MHz).

ITS, OSM, and Japanese Administration engineers used a Draft New Recommendation (M.1177),

Figure 1. Set-up for a joint US-Japan maritime radar emission spectrum measurement at the ITS Table Mountain facility near Boulder. The measurements were performed using new ITU Recommendation techniques primarily authored by an ITS engineer (photo by F.H. Sanders).

Figure 2. A meeting of Working Party 8B in Geneva in 2004. Critical US Administration spectrum interests are routinely supported by ITS engineers at this and other ITU meetings (photo by F.H. Sanders).

primarily authored by an ITS engineer, to perform measurements on emissions on five maritime S-band and X-band radars. The measurements were performed at the Table Mountain facility north of Boulder (see Figure 1 above). Results will be used in future Contributions to WP-8B by both the US and Japanese Administrations (see Figure 2).

Recent Publications

F. Sanders, R. Hinkle, and B. Ramsey, "Measurement Procedures for the Radar Spectrum Engineering Criteria (RSEC)," NTIA Report 05-XX, in progress.

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Support to Private Sector Telecommunications Activities:

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 Recommendations and associated U.S. industry standards.

The Institute has a long and distinguished history of leadership, technical contributions, and advocacy of U.S. Government and industry proposals in international and related national telecommunication standards committees. These activities are focused in the International Telecommunication Union (ITU) — the United Nations-affiliated standards organization responsible for the cooperative planning and interoperation of public telecommunication systems and services worldwide. The ITU's Telecommunication Standardization Sector (ITU-T) develops international standards (Recommendations) addressing technical, operating, and tariff questions relating to all aspects of wireline telecommunications. ITU-T Recommendations have a strong impact on both the evolution of U.S. telecommunications infrastructures and the competitiveness of U.S. telecommunications products in international trade.

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

In FY 2004, the Institute provided leadership in two key ITU-T groups: Study Group 13 Working Party 4 (Network Performance and Resource Management) and Study Group 9's Working Group on Quality Assessment. Study Group 13 develops international standards (Recommendations) addressing Optical Transport Network (OTN), Multi-Protocol Label Switching (MPLS), Ethernet, and IP-based technologies, all of which are expected to play an important role in the realization of multi-service Next-Generation Networks (NGNs). SG 13/WP 4 develops international standards on network performance and resource management for all of the NGN core technologies. SG 9's Working Group on Quality Assessment defines quality objectives for integrated broadband cable networks and television and sound transmission. Within that group ITS chairs Question 21/9, "Objective and Subjective Methods for Evaluating Audiovisual Quality in Multimedia Services." ITS also provides leadership and technical contributions in the ITU affiliated Video Quality Experts Group (VQEG) and the Alliance for Telecommunications Industry Solutions (ATIS) Network Performance, Reliability and Quality of Service Committee (PRQC), formerly T1A1. VQEG works in conjunction with ITU-T SGs 9 and 12 and ITU-R WP6Q (Broadcasting Services — Performance Assessment and Quality Control) to develop objective, computer implementable, perception-based video quality metrics (VQMs) that emulate the human visual system. PRQC develops national standards and contributes strongly to ITU-T in all of these technology areas.

During FY 2004, the Institute's SG 13 leadership contributed to the completion and approval of eight ITU-T Recommendations, providing new specifications on OTN performance, IP network traffic and congestion control, MPLS network performance, IP network call processing, and other topics of importance to NGN. ITS presented key results of this work in an ITU-T workshop session, "Specification and Signaling of IP QoS Classes," summarized at http://www.itu.int/ITU-T/worksem/qos/program.html. ITS also provided technical leadership supporting U.S. Government and industry preparation for the World Telecommunication Standardization Assembly (WTSA), a quadrennial meeting at which the ITU-T Member States determine the objectives, structure, work methods, and senior leadership of ITU-T for the following 4-year Study Period. ITS participated in the formation and technical

management of the ITU-T NGN Focus Group, a transitional standards organization established by the ITU-T Director to accelerate NGN standardization work during the "interregnum" period surrounding the WTSA. As input to the WTSA, ITS developed a summary Recommendation that concisely defines the scope, application, and interrelationships among the over 30 performance Recommendations developed by SG 13/WP 4. The Institute also contributed strongly to the development of a key U.S Government contribution to WTSA, proposing the creation of a new NGN Study Group for the 2005-2008 Study Period. Industry leaders believe NGN standardization will be very important in defining new network technologies capable of fully integrating today's wired telephony, video, wireless, and Internet infrastructures and services — and motivating the capital investment needed to deploy them.

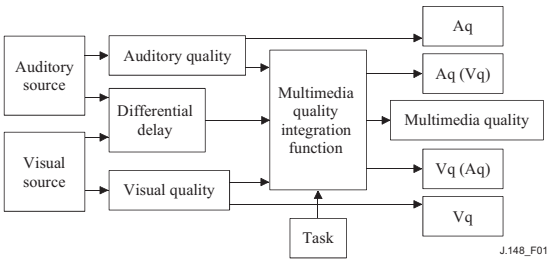
ITS leadership in PRQC contributed to the completion and approval of five new ATIS specifications on network reliability performance and emergency telecommunications service (ETS), two new ATIS specifications on video communication quality, and numerous U.S. contributions to ITU-T on related topics. The new ATIS specifications address U.S. industry needs and advance key goals of both the DoC and the Department of Homeland Security. The Institute's technical contributions to PRQC included contributions on QoS specification, QoS interoperability, and IP network QoS signaling. One contribution of particular import identified interoperability issues and evaluated possible mapping solutions for QoS interworking between wireless and wireline IP networks. ITS participated with other leaders in implementing a major reorganization of the ATIS standards committees, contributing to a more product-driven ATIS standards management regime and elevating the former Committee T1 Technical Subcommittees to independent standards development organizations. ITS helped shape the technical objectives for a newly-formed ATIS NGN Focus Group, promoting coordination of U.S. NGN standardization efforts with ongoing ITU-T work.

ITS has co-chaired the ITU Video Quality Experts Group since its formation in 1997. VQEG enables video experts from many countries to collaborate in developing and evaluating video quality metrics, and its results strongly impact the standardization of VQMs in both ITU-T and ITU-R. The group works primarily via an e-mail reflector, publicly accessible at http://www.VQEG.org. During FY 2004 the number of participants subscribed to this reflector grew to 380. ITS chaired two physical meetings and several conference call meetings in FY 2004.

During FY 2004, ITU-T and ITU-R approved several Recommendations based on work supported by ITS. Most noteworthy are ITU-T Recommendation J.149, "Methodological Framework for Specifying Accuracy and Cross-Calibration of Video Quality Metrics (VQM)," and ITU-T Recommendation J.144 Revised, "Objective Perceptual Video Quality Measurement Techniques for Digital Cable Television in the Presence of a Full Reference."

J.144 Revised was the result of a multi-year VQEG effort to evaluate "full reference" VQMs for assessing standard definition television. During FY 2004, VQEG undertook a complementary "reduced reference" validation test for standard definition television, to be completed in FY 2005. VQEG also launched a major new initiative in the area of multimedia quality assessment. ITS leadership was instrumental in forming the Joint Rapporteur Group on Multimedia Quality Assessment (JRG-MMQA), a cross-cutting ITU-T standards body that will unite the video quality expertise of SG 9 with the audio quality expertise of SG 12 in a cooperative effort to develop objective, perception-based metrics for combined audio and video in mobile and PC environments. This group is co-chaired by ITS.

The figure below (from Recommendation J.148) illustrates the basic components of a multimedia quality assessment model.



Basic components of a multimedia quality assessment model.

Recent Publication

A. Webster, Ed., "ITU-T Tutorial on Objective Perceptual Assessment of Video Quality: Full Reference Television," 2004.

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Newly installed stairs leading to an 18.3-meter (60-foot) parabolic dish antenna at the Table Mountain field site (photograph by J.D. Ewan).

ITS Tools and Facilities

Advanced Antenna Testbed

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

Configurable Testbed Parameters

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

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

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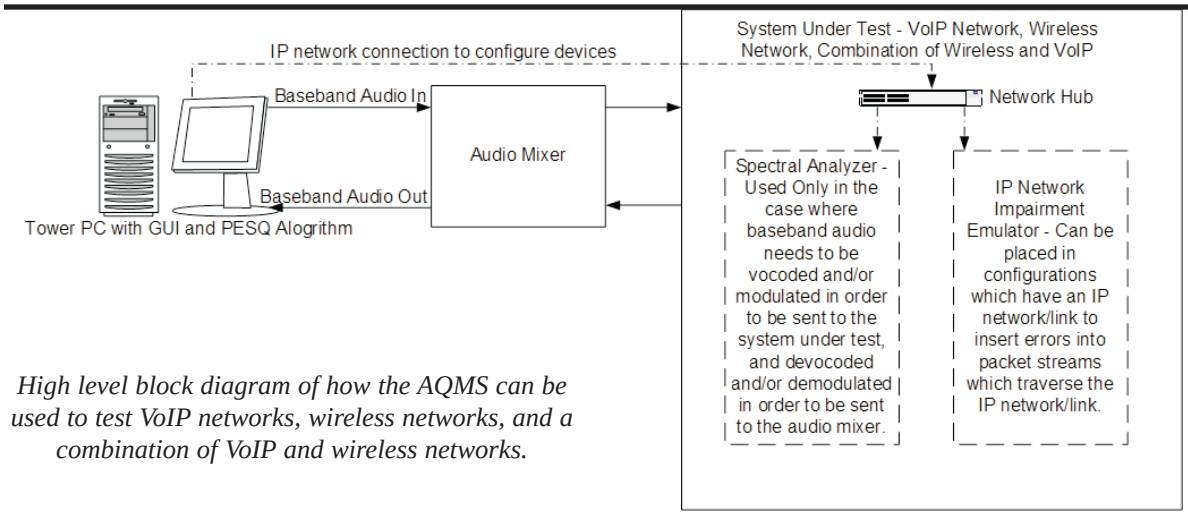
Audio Quality Measurement System (AQMS)

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



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

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

So far this system has been used to evaluate the voice quality of a Project 25 VoIP combination system which is comprised of two ultra/very high frequency (UHF/VHF) repeaters which have the capability to transmit over IP links. It has also been used to evaluate the voice quality of VoIP-capable telephones that require the use of session initiated protocol (SIP) or H.323 to make a telephone call. This test setup supplements the acoustically coupled audio test setup discussed by D.J. Atkinson on pp. 22-23 of this report.

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Audio-Visual Laboratories

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

Laboratory equipment supports standard-definition (SD) and high-definition (HD) video signals, as well as monophonic, stereophonic, and 5.1 channel audio streams. Signals are acquired with high-quality microphones and cameras. Recording and playback devices include studio-quality analog and digital video tape recorders with two to eight audio channels, digital audio tape machines, CD players, and analog audio cassette machines. These systems are augmented with several computer-based digital audio and video systems and a set of high quality Analog-to-Digital and Digital-to-Analog converters. Analog audio mixing, filtering, and equalizing equipment is available. An array of digital audio and video encoders and decoders are available, as well as an HDTV modulator and demodulators. Analog and digital audio and video routing switches 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.

Two separate rooms with controlled acoustic and visual environments are available for the subjective testing of audio and video signals. These environments are specified in International Telecommunication Union — Telecommunication Standardization Sector (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. A third room is used exclusively for the presentation of HD video signals.

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

Lab activities include objective estimation of audio and video quality, and subjective testing of audio and video quality. Random access digital audio video playback systems coupled with discrete-time

and continuous-time electronic data entry systems greatly facilitate many of the subjective testing activities. Because multiple subjective testing rooms are available, the laboratory can support conversation, teleconferencing, and video teleconferencing tests as well as viewing and listening tests. Objective video quality estimation software, written in C++ and MATLAB, processes video signals in accordance with American National Standards Institute (ANSI) T1.801.03-2003, resulting in estimates of video quality that show good correlation with subjective test results. Several different objective speech and audio quality estimation algorithms are available, including those defined in ANSI T1.518, ITU-T Recommendation P.862, and ITU-R Recommendation BS.1387. The labs support both batch-mode and real-time objective quality estimation.

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Digital Sampling Channel Probe

The digital sampling channel probe (DSCP), designed and patented at ITS, is used to characterize the wideband propagation characteristics of the radio communication channel. The probe, consisting of a transmitter, receiver, and data acquisition system, is used to make complex impulse response measurements. The DSCP digitizes a received pseudo-noise signal at an intermediate frequency (IF) and then post processes the data. The digital system is capable of collecting impulse response data on multiple channels every 600-800 µs. This allows characterization of the Doppler spectrum and time variability of the mobile channel for high frequency systems (up to 5.8 GHz). Historically the DSCP has been employed extensively for channel characterization of cellular and personal communications services (PCS). ITS has expanded the probe to 8 channels capable of mobile phased array or multiple input, multiple output (MIMO) measurements. Also available is a wide-bandwidth, high-frequency probe, particularly suited for high resolution requirements such as wireless local area network (LAN) applications up to 30 GHz. For a more detailed description of the measurement systems and applications, see this website: http://flattop.its.bldrdoc.gov/rcirms/

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Green Mountain Mesa Field Site

The main Department of Commerce Boulder Laboratories campus contains a field site used for outdoor wireless network research. The site is connected to the ITS laboratories via both fiber optic and 802.11 links. The fiber optic link is currently providing access to the ITS local area network (LAN) while the 802.11 link connects this field site to the ITS Wireless Networks Research Center (see p. 69). The site can provide six independent duplex fiber channels to the ITS lab. This allows research to be conducted over an isolated 1-mile outdoor Wi-Fi link. The fiber connectivity provides a LAN connection to the outdoor wireless router and for capability to operate remote data collection equipment. The outdoor router, located on an 80-foot tower, provides long range 802.11 links to other Commerce field sites. Currently these links provide 802.11b services and are also used for network performance testing.

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

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

ITS maintains a test capability for measuring the performance of land-mobile radio systems that comply with the Telecommunications Industry Association's TIA-102 and TIA-603 series of standards through its Interoperability Research Laboratory (IRL). The IRL also supports laboratory investigation of "interim solution" interoperability devices.

The measurement capabilities include the usual receiver and transmitter measurements such as receive sensitivity, co-channel and adjacent-channel rejection, spurious response rejection, and transmitter emissions mask. Highly accurate measurements are made possible by laboratory grade signal generators, fading simulators, spectrum and vector signal analysis tools, and an RF shielded enclosure. The lab possesses both models of TIA-102 (Project 25) capable communications system analyzers which can decode various aspects of the link control information, such as network access code, talk group identification, and status bit. Demodulated speech

samples can also be collected and scored for audio clarity using the ITU's PESQ algorithm.

The primary use for this capability is interoperability testing between TIA-102 radios of different manufacture and backward compatibility testing between TIA-102 radios and legacy FM systems. Other applications may be possible, for example, routine performance measurements or more niche applications, such as VoIP radio repeaters or baseband audio interoperability devices. This capability is available on a first-come, first-served basis by both NTIA and other agencies.

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

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 various standards committees. Some highlights of ITS Internet Services include:

- Information about ITS programs and projects. Available at http://www.its.bldrdoc.gov/home/projects.html
- An ITS organization chart and a complete listing of ITS staff with contact information. Available at http://www.its.bldrdoc.gov/home/organization.html
- Recent ITS publications including NTIA Reports, special publications, and journal articles. Available at http://www.its.bldrdoc.gov/pub/pubs.html
- Radio propagation data. Available at http://www.its.bldrdoc.gov/home/data/radio_propagation_data/
- Radio propagation software. Available at http://www.its.bldrdoc.gov/home/software/
- Telecommunications Analysis Services. Available at http://www.its.bldrdoc.gov/tas/
- Video Quality Metric Software. Available at http://www.its.bldrdoc.gov/n3/video/vqmsoftware.htm
- Information about ITS-sponsored events such as ISART. Available at http://www.its.bldrdoc.gov/home/conferences/
- Anonymous FTP distribution of some ITS developed software programs. Available at ftp.its.bldrdoc.gov

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ITS Local Area Network

ITS maintains a highly flexible local area network (LAN) to support intranetworking services and laboratory interconnection. A structured cabling system interconnects all offices and laboratories with both optical fiber and Category 5 twisted-pair cabling to support high-bandwidth communications on demand. Over 200 devices are supported on 10Base-T and 100Base-TX Ethernet segments. Connections can also be made to laboratory test beds featuring synchronous optical network/asynchronous transfer mode (SONET/ATM). This provides ITS with great flexibility and rapid reconfiguration capability for new programmatic needs.

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Mobile Radio Propagation Measurement Facilities

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

A suite of measurement software is maintained for calculating mobile propagation metrics from the impulse response data. Typical metrics are power delay profiles, delay spread, received power versus bandwidth, Doppler spectrum and coherence bandwidth.

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Pulsed CW Radar Target Generator

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

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Radio Noise Measurement System

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

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

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

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

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Radio Spectrum Measurement System (RSMS)

The ITS Radio Spectrum Measurement System (RSMS) 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. RSMS 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 detection devices. Measurements can take place in a laboratory or in the field, or 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 kWatt diesel generator, as well as Internet connections, fiberoptic control lines, multiple power outlets, and overhead cable racks. The control and acquisition software is fully developed by ITS so that new and innovative measurement techniques can be easily altered to meet 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 to expand on existing measurement capabilities.

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SIPRNET Capability

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

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Spectrum Compatibility Test and Measurement Sets

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

unavailable for use. This includes situations such as laboratory tests using interference from ship or aircraft mounted radars or communications systems. In both situations a system is needed that simulates the spectral emissions of other devices with a wide range of latitude. Examples include determining the thresholds at which types of interference from communication transmitters are manifested as interference effects in radar receivers, and testing the response of a dynamic frequency selection wireless communication device to detect types of radar energy without actually setting up real radars for the test.

To meet these needs, ITS engineers have developed two different types of interference generators. The first is the Broadband Arbitrary Waveform Transmitter (BAWT) that is used 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 into a target system's antenna to more accurately gauge its response to a real interference situation.

In cases where ITS can gain access to the emissions from a particular transmitter, the transmitter's emissions can be digitized using high-speed samplers. The digitized waveforms (in bandwidths up to 30 MHz and at frequencies as high as 26 GHz) are stored. The amplitudes, frequency components, and phase components of the signals are recorded for later playback by arbitrary waveform generators and selected RF signal generators. The advantage of this arrangement is that very complex waveforms may be replicated with complete confidence in the fidelity of the simulated signal to the characteristics of the original signal from which it has been derived.

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

Table Mountain Field Site and Radio Quiet Zone

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

- **Spectrum Research Laboratory** — A state-of-the-art facility for research into radio spectrum usage and occupancy. Radio Quiet restrictions ensure that no signal incident on the mesa overpowers any other, and an antenna farm provides both directional and non-directional antennas spanning a broad range of frequencies.

- **Open Field Radio Test Site** — A flat-topped butte with uniform 2% slope, Table Mountain is uniquely suited for radio experiments. It has no perimeter obstructions and the ground is relatively homogeneous. This facilitates studying outdoor radiation patterns from bare antennas or antennas mounted on structures.

- **Mobile Test Vehicles** — There are several mobile test equipment platforms available at the mesa, ranging from 4-wheel drive trucks to full-featured mobile laboratories.

- **Large Turntable** — A 10.4-meter (34-foot) diameter rotatable steel table mounted flush with the ground. Laboratory space underneath houses test instrumentation as well as the new control equipment and motors to rotate the turntable. This facility can be operated remotely by computer.

- **18.3 Meter (60 Foot) Parabolic Dish Antennas** — These two antennas are steerable in both azimuth and elevation and have been used at frequencies from 400 MHz to 6 GHz.

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

The Table Mountain Research program supports a number of research activities, e.g., studying the effects of radio propagation on the integrity of digital signal transmission and video quality, environmental and man-made noise, verification of antenna propagation models, and the development of measurement methods needed to assess efficient spectrum occupancy and usage (see pp. 10-11).

Partnerships and cooperative research activities are encouraged at the site. Other organizations currently using the facilities include the National Oceanic and Atmospheric Administration (NOAA), the U.S. Geological Survey (USGS), the Deep Space Exploration Society, and Coherent Technologies.

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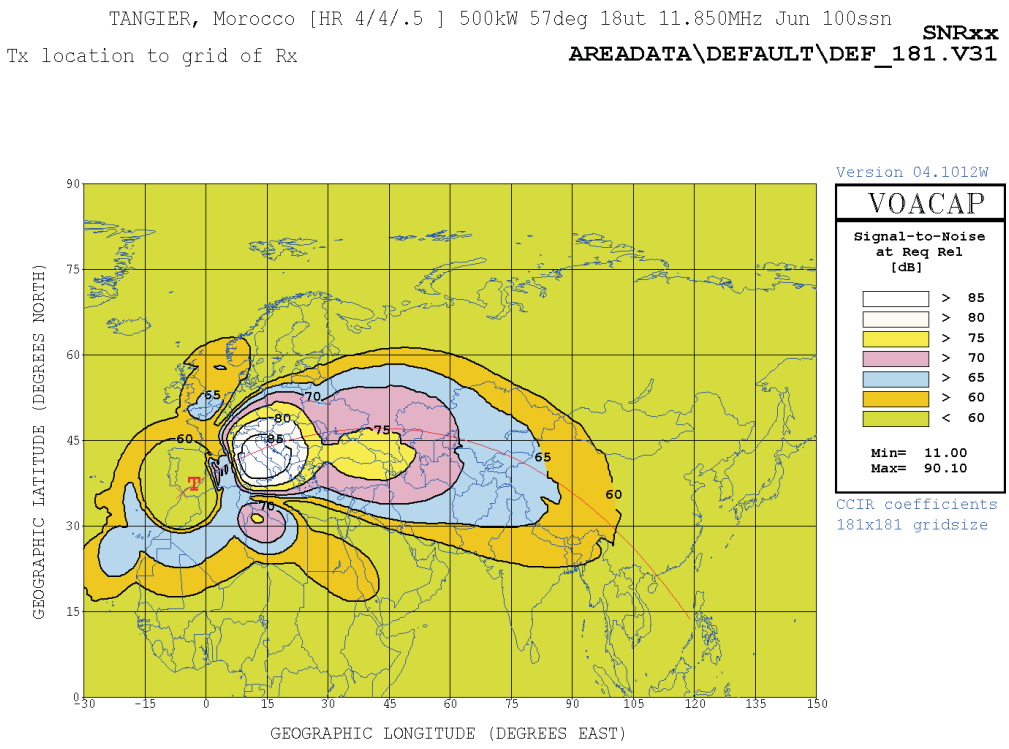
Telecommunications Analysis Services

Telecommunications Analysis Services (TA Services) provides the latest engineering models and research data developed by ITS to industry and other Government agencies via a web-based interface (http://flattop.its.bldrdoc.gov). Designed to be both user-friendly and efficient, it offers a broad range of programs that allow the user to design or analyze the performance of telecommunications systems. Currently available are: on-line terrain data with 1-arc-second (30 m) for CONUS and 3-arc-second (90 m) resolution for much of the world, and GLOBE (Global Land One-km Base Elevation) data for the entire world; 2000 census data, 1990 census data (also 1997 updated); Federal Communications Commission (FCC) databases; and geographic information systems (GIS) databases (ARCINFO). TA Services has developed models that predict communication system coverage and interference for many broadcast applications. New models in the GIS environment for personal communications services (PCS) and Local Multipoint Distribution Services (LMDS) have been developed (see Telecommunications Analysis Services, pp. 36-37). The TA Services computer has about 210 GB of storage capacity.

The following is a brief description of some programs available through TA Services.

HAAT – Calculates Height Above Average Terrain for an antenna at a specified location.
PCS/LMDS – Allows the user to create or import surfaces which may include terrain, buildings, vegetation, and other obstructions in order to perform line of sight (LOS) and diffraction studies.
FCCFIND, FMFIND, TVFIND, AMFIND, and TOWERFIND – Allows the user to search the FCC database for particular stations or by search radius around a point of interest.
PROFILE – Extracts path profiles according to user-specified input parameters. After the data is extracted, either the individual elevations or an average elevation along the profile can be obtained. A user can also receive plots of the profiles adjusted for various K factors. For microwave links, Fresnel zone clearance can be determined so that poor paths can be eliminated from a planned circuit or network.
SHADOW – Plots the radio LOS regions around a specified location in the United States using digitized topographic data. The program shows areas that are LOS to the base of the antenna, areas that are LOS to the top of the antenna, and areas that are beyond LOS to the antenna.
TERRAIN – Plots terrain elevation contours from any of the terrain databases available (1-arc-second SDTS for CONUS, 3-arc-second USGS, and GLOBE for the whole world).
COVERAGE – Calculates the received signal levels along radials that are spaced at user-defined intervals of bearing around the transmitter. The program lists the contours of signal coverage of the transmitter along each radial and lists distances to user-specified contours for each radial. Either the FCC broadcast rules or the ITS Irregular Terrain Model can be chosen for calculations.
CSPM – Determines the system performance of mobile and broadcast systems in detailed output plots of signal intensity, as shown in the figure. 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 Irregular Terrain Model 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



Example of VOACAP HF area coverage prediction.

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 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).

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Wireless Networks Research Center (WNRC)

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

The WNRC contains an experimental IEEE 802.11b wireless local area network (WLAN). ITS has conducted a series of wireless Voice over IP (VoIP) tests utilizing this infrastructure. The WLAN resources include IP packet logging equipment that can be used in network measurements. ITS has added a code domain analyzer (CDA) measurement capability to the WNRC. The CDA is used to collect both short and long term Walsh channel data for any target IS-95 base station. 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 TIA TR-46.2. ITS also has the capability to simulate PCS interference using a series of ITS implemented interference models.

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Engineer from the Japanese Administration preparing to perform joint US-Japan maritime radar emission spectrum measurements at the Table Mountain field site (photograph by F.H. Sanders).

ITS Projects in FY 2004

NTIA Projects

Audio Quality Research
Identify and contribute to selected open questions in the areas of digital speech and audio compression, transmission, and quality assessment. Investigate quality assessment and robust speech coding questions related to the deployment of VoIP systems. Deliverables include technical publications, algorithms, software, upgrades to the HDTV laboratory, and technical presentations and laboratory demonstrations as requested.
Project Leader: Stephen D. Voran (303) 497-3839
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Broadband Wireless Research
Continue development of state-of-the-art measurement systems for collecting broadband radio-wave propagation data. Provide measurement tools and propagation data used for simulation of the spectral efficiency of proposed communication systems. Deliverables include NTIA Reports and a journal article.
Project Leader: Peter B. Papazian (303) 497-5369
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Broadband Wireless Standards
Develop technical means to improve predictions of signal coverage and interference for 3G wireless services through support to ITU-R, TIA TR-8 (Project 25), and other organizations. Building on previous ITS work, develop propagation model comparisons, apply the models to data sets, determine differences during comparison, document results, and start enhancement to ITM of effective antenna height. Deliverables include model enhancements, and standards contributions and leadership.
Project Leader: Paul M. McKenna (303) 497 3474
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Electromagnetic Compatibility Research Support
Advance research in electromagnetic compatibility issues with the technical subcommittee of the Interdepartment Radio Advisory Committee (IRAC); the US Working Party 8B of ITU-R; and the U.S. Administration in ITU-R Study Group 8 and ITU-R Working Party 8B. Provide technical inputs in the form of NTIA Reports; ITU Contributions; presentations at national and international meetings; and participation in national and international meetings.
Project Leader: Frank H. Sanders (303) 497-7600
e-mail fsanders@its.bldrdoc.gov

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

Network Interoperability
Derive and use a systems engineering-oriented framework to better understand, and address, the integral components/elements of interoperability and their associated technical issues; analyze real world interoperability issues in the laboratory and use the results to ensure the utility of the framework. Design and conduct related experiments in the ITS Interoperability Research Laboratory. Deliverables include contributions to Project 25/TR-8 meetings.
Project Leader: Randall S. Bloomfield (303) 497 5489
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Network Performance
Provide objective, expert leadership and key technical contributions in ITU T and related U.S. industry committees responsible for developing broadband network performance, Quality of Service (QoS), Operation, Administration and Maintenance (OAM), and resource management standards.
Project Leader: Neal B. Seitz (303) 497 3106
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Networking Technology
Characterize and analyze the fundamental aspects of networks and network interoperability. Continue the development of networking technology methodologies and tools to address network management and network security/protection issues. Deliverables include a technical report, software, and a user manual.
Project Leader: David J. Atkinson (303) 497 5281
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OSM Spectrum Efficiency and Support
Provide support to the OSM initiative to improve spectrum efficiency and effectiveness in Federal mobile radio services in the 162-MHz band in the Washington, DC, area. Finish a Phase 1 report on

the level of service (signal capacity) provided by current Federal radio systems, and begin developing alternative shared system designs to illuminate the advantages and disadvantages of various architecture options.
Project Leader: Robert J. Matheson (303) 497-3293
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Policy Support
Provide engineering and technical support to NTIA in telecommunications policy development. Provide support on various near-term issues, including broadband wireless access, 3rd generation wireless systems, privacy issues, information technology advances, and critical informal protection.
Project Leader: Alan W. Vincent (303) 497 3500
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RSMS Enhancements
Develop and maintain software, hardware, systems, and equipment to meet the immediate needs of FY 2004 operations tasks.
Project Leader: Randy Hoffman (303) 497 3582
e-mail rhoffman@its.bldrdoc.gov

RSMS 4th Generation Development
Provide new and innovative measurement tools for current and future Radio Spectrum Measurement System (RSMS) capabilities. Major goals are the ability to easily expand measurement and analysis capabilities and to modify the equipment configuration in the field.
Project Leader: 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: Randy Hoffman (303) 497 3582
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Table Mountain Modernization
Provide upkeep and maintenance of the Table Mountain field site. Provide logistical support to other projects associated with the Table Mountain field site.
Project Leader: John D. Ewan (303) 497-3509
e-mail jewan@its.bldrdoc.gov

Table Mountain Research
Utilize the Table Mountain field site and radio quiet zone to support fundamental research into the nature, interaction, and evaluation of telecommunication devices, systems, and services. Actively solicit research proposals that will serve to expand the knowledge base available to the institute, help identify emerging technologies, and provide for the development of new measurement methods needed to study the characteristics of new devices and systems based on this technology.
Project Leader: J. Wayde Allen (303) 497-5871
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Third Generation Wireless
Develop error models that accurately characterize the mobile radio link and estimate the effect of the radio channel on fundamental wireless network performance parameters, e.g., throughput, delay, and loss, to be used by both industry and Government. Deliverables include reports and presentations which disseminate the results of tasks to the public.
Project Leader: Robert J. Achatz (303) 497 3498
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Third Generation Wireless Interference Modeling and Characterization
Building on previous ITS work, develop interference models for viable PCS technologies, and verify and validate the models using software analysis and hardware measurements. Apply the models in characterizing PCS interference for 3G architectures, and determine operational guidelines and other practical means of mitigating observed interference effects. Deliverables include contributions to G3GRA (formerly T1P1.2) and ITU-R TG-8/1.
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 such as direct broadcast satellite, digital television, HDTV, video teleconferencing, telemedicine, and e-commerce, and actively transfer this technology to other Government agencies, end-users, standards bodies, and the U.S. telecommunications industry. Deliverables include technical publications, video quality measurement algorithms and software, laboratory upgrades, and technical standards contributions.
Project Leader: Stephen Wolf (303) 497 3771
e-mail swolf@its.bldrdoc.gov

Other Agency Projects

Department of Commerce/National Institute of Standards and Technology

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

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

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

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

Department of Justice/Wireless Management Office

Land Mobile Radio (LMR) Usage Statistics and Engineering Studies
Assist the Wireless Management Office's high-level system design efforts aimed at planning the Justice Wireless Network (JWN) by characterizing traffic among Justice law enforcement agencies in selected urban areas, and by performing other research and engineering activities as requested.
Project Leader: Eldon J. Haakinson (303) 497 5304
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Federal Highway Administration

Spectrum Regulation and Engineering Support
Provide technical support in the development of a differential Global Positioning System (DGPS) radio beacon network for nationwide availability of precision navigation and positioning radio signals. Support includes frequency assignment searches of Government databases; analysis of propagation and interference issues; and electromagnetic compatibility analyses.
Project Leader: John J. Lemmon (303) 497 3414
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Federal Railroad Administration

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

Miscellaneous Federal and Non Federal Agencies

Telecommunications Analysis Services
Develop, maintain, and make available to other Government agencies and to the public, through user friendly computer programs, a large menu of engineering models, scientific and informative databases, and other useful communication tools.
Project Leader: Gregory R. Hand (303) 497 3375
e-mail ghand@its.bldrdoc.gov

National Communications System

Coordination of Land Mobile Radio Deployment Initiatives
Provide engineering studies for the Public Safety Wireless Network (PSWN) to evaluate interference to public safety systems, to compare system architectures, to evaluate system components for interoperability, and to support additional projects as directed by PSWN.
Project Leader: Eldon J. Haakinson (303) 497 5304
e-mail ehaakinson@its.bldrdoc.gov

Digital Land Mobile Radio Standards Development
Assist NCS in developing a comprehensive set of interoperability standards for digital land mobile radio to support law enforcement, public safety, and other critical NS/EP operations. Serve as NCS representative on the Project 25 steering committee and the TIA TR 8 committee, chair the Encryption Task Group, provide systems engineering support to other Task Groups, develop Project 25 Phase 3 security standards, and coordinate Project 25 activities with other Federal users.
Project Leader: William J. Pomper (303) 497 3730
e-mail wpomper@its.bldrdoc.gov

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

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

Standards Promulgation Support
Advance NS/EP standards development and implementation initiatives in national and international forums; promulgate and coordinate results. Deliverables include project planning documents, technical leadership and administrative assistance in standards development activities, biannual program review presentations, and quarterly project status reports.
Project Leader: Neal B. Seitz (303) 497 3106
e-mail nseitz@its.bldrdoc.gov

Voice Over Packet and Strategic Interoperability
Assist NCS and its member organizations in defining, promoting, and implementing telecommunication technology enhancements supporting NS/EP and critical infrastructure protection needs. Participate in the TIA TR 41 Standards Formulating Group with emphasis on IP telephony gateways and their supporting infrastructure, develop technical contributions to ensure that user interfaces being developed for IP telephony satisfy NS/EP communications requirements, conduct a research and development effort to examine how TR 41 standards can best be exploited to meet NS/EP requirements, and evaluate aspects of strategic interoperability.
Project Leader: Robert Stafford (303) 497 7835
e-mail rstafford@its.bldrdoc.gov

Packet Wireless Applications
Identify emerging technologies with strong NS/EP potential, and objectively evaluate their capabilities and limitations in laboratory and field trials under representative (simulated) emergency conditions. As necessary, refine and apply existing instrumentation and methods for wireless network discovery.
Project Leader: Christopher Redding (303) 497 3104
e-mail credding@its.bldrdoc.gov

U.S. Army Information Systems Engineering Command (ISEC)

Comparison of Radio Propagation Models' Predictive Accuracies Using Measured Propagation Data
Compare two radio propagation prediction models: TIREM v3.15 and COVMOD. Provide statistics of each model's prediction error relative to the measured data.
Project Leader: Paul M. McKenna (303) 497 3474
e-mail pmckenna@its.bldrdoc.gov

U.S. Coast Guard

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

Cooperative Research and Development Agreements (CRADAs)

Lucent Bell Laboratories

Provide Lucent with measured propagation data used for simulation of the spectral efficiency of proposed MIMO communication systems. Provide technical assistance in analyzing propagation data to measure the performance of MIMO communication systems.
Project Leader: Peter B. Papazian (303) 497-5369
e-mail ppapazian@its.bldrdoc.gov

Motorola/Freescale, Inc.

Investigate the interference potential of various UWB waveforms. Generate a range of waveforms representative of existing and proposed UWB systems. Develop measurement procedures and analyses to characterize the interfering UWB signals. Assess UWB interference susceptibility of C-band television receivers. Deliverables include an NTIA Report.
Project Leader: Michael G. Cotton (303) 497-7346
e-mail mcotton@its.bldrdoc.gov

Savi Technology

Investigate the interference effects of 400 MHz radio frequency identification (RFID) tags on analog, FM voice radio communications in that part of the spectrum. Perform tests at the ITS laboratory and the Table Mountain field site. Deliverables include a report on the final test results.
Project Leader: Frank H. Sanders (303) 497-7600
e-mail fsanders@its.bldrdoc.gov

Attendees at the 2004 International Symposium on Advanced Radio Technologies mingling in the lobby outside the auditorium (photograph by W.A. Kissick).

Assistant Secretary Michael Gallagher delivering a speech at the rededication ceremony, part of the celebration of the 50th anniversary of the Boulder Laboratories (photograph by M. Brunner).

ITS Outputs in FY 2004

NTIA Publications

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

> In radio frequency (RF) measurements the gain (or loss) of the signal path connecting the measurement equipment to the measurement reference plane must be accounted for. This tutorial paper discusses the various definitions of gain, and how to determine the gain using either a calibrated signal generator, noise source, or network analyzer.

J.W. Allen, T.X Brown, D.C. Sicker, and J. Ratzloff (Eds.), "Proceedings of the International Symposium on Advanced Radio Technologies, March 2-4, 2004," NTIA Special Publication SP-04-409, Mar. 2004.

> No abstract available.

M.E. DeWeese, M.A. Luebs, and H.L. McCullough (Eds.), "Significant papers from the first 50 years of the Boulder Labs," NTIA Special Publication SP-04-416 and NIST IR 6618, Aug. 2004.

> The Department of Commerce Boulder Labs were dedicated on September 14, 1954, in the shadow of World War II, and at the dawn of a bright future. This volume presents a snapshot of our research accomplishments in the half century since then. During this time, the Boulder Labs have evolved from the National Bureau of Standards' Central Radio Propagation Laboratory to today's National Institute of Standards and Technology, National Oceanic and Atmospheric Administration, and National Telecommunications and Information Administration's Institute for Telecommunication Sciences. The papers we have collected represent the most significant work of all the agencies of the Boulder Labs, whatever their name at the time of publication.

P. Papazian and M. Cotton, "Relative propagation impairments between 430 MHz and 5750 MHz for mobile communication systems in urban environments," NTIA Report TR-04-407, Dec. 2003.

> Radiowave propagation measurements made in an urban area of Denver, Colorado, are described. Wideband, impulse response measurements were made at 4 carrier frequencies from 420 MHz to 5750 MHz. Basic transmission loss slope and delay spread statistics are used to characterize propagation conditions. By analyzing these results versus carrier frequency the relative propagation impairments for communication systems at 430, 1350, 2260 and 5750 MHz are compared. It was found that the path loss slope increased on average by 11 dB/decade and the delay spread decreased from 33% to 65% over the decade of frequencies measured.

M.H. Pinson and S. Wolf, "The impact of monitor resolution and type on subjective video quality testing," NTIA Technical Memorandum TM-04-412, Mar. 2004.

> This document compares subjective video quality test results from a professional cathode ray tube (CRT) television monitor with that of a consumer liquid crystal display (LCD) video phone monitor. The CRT monitor supported the full ITU R Recommendation BT.601 resolution (720 x 486) while the LCD monitor only supported Common Intermediate Format (CIF) resolution (352 x 288). The subjective results from the two tests are very similar, with the only significant difference being that the CIF monitor masks impairments that appear in only one of the two interlaced fields.

S. Wolf, "Color correction matrix for digital still and video imaging systems," NTIA Technical Memorandum TM-04-406, Dec. 2003.

> This document discusses a method for correcting inaccurate color output by digital still and video imaging systems. The method uses a known reference image together with a least squares algorithm to estimate the optimal color channel mixing matrix that must be applied to the output images in order to correct their color inaccuracies. The techniques presented in this document will provide users of digital photography and video equipment with an automated tool for correcting color output. For instance, digital photography users currently may try to correct color distortions in their images by trial and error using photo editing software.

However, these correction procedures are time consuming and subjective and do not normally allow for arbitrary mixing of the color channels. The automated color correction matrix computation presented in this document allows each color component in the corrected image (e.g., red) to be calculated as a linear summation of a DC component and all the color components (e.g., red, green, and blue) in the uncorrected image. Methods to correct non linearities in the color response of digital imaging systems are also discussed.

Outside Publications

Articles in Conference Proceedings

R.A. Dalke, "Analytical description of time and spectral characteristics of ultrawideband signals," in *Proc. of Wireless 2004: The 16th International Conference on Wireless Communications*, Calgary, Jul. 2004.

A variety of communications devices using ultra-wideband (UWB) signals have been proposed. An understanding of the effects of such devices on more traditional RF systems is essential to both system designers and regulators. The Institute for Telecommunication Sciences has analyzed the characteristics of UWB signals from a variety of proposed devices. In this paper we describe the statistical characteristics of emissions from a fixed time-base dithered UWB device based on a theoretical analysis of the emitted signal.

J. Kub and E. Nelson, "LabVIEW with databases automates testing of land mobile radios for public safety," finalist, Virtual Instrumentation Applications paper contest, NIWeek 2004, Austin, TX, Aug. 2004.

Public Safety agencies at all levels of government (federal, state, local, and tribal) rely upon land mobile radios (LMRs) for day-to-day and emergency wireless communications. The advent of digital Project 25 LMRs has forced system designers to exhaustively characterize the interactions between Project 25 and legacy analog systems. These interference rejection tests, performed manually, were time-consuming and are prone to human error. However, the use of NI LabVIEW automation ensured accurate, cost-effective, and repeatable results through the use of a database library of selectable GPIB and RS-232 instrument commands and database measurement reporting.

G. Patrick, C. Hoffman, and R. Matheson, "Signal capacity modeling for shared radio system planning," in "Proceedings of the International Symposium on Advanced Radio Technologies: March 2-4, 2004," J.W. Allen, T.X Brown, D.C. Sicker, and J. Ratzloff (Eds.), NTIA Special Publication SP-04-409, Mar. 2004.

Almost every major Federal agency operates an independent mobile radio system in the 162-174 MHz band to provide critical radio communications with its own agents. Last year, NTIA began a joint OSM/ITS Spectrum Efficiency Initiative, which includes a study of whether a shared radio system (e.g., a trunked system) could functionally and advantageously replace most of the specialized single-agency radio systems. The first phase of this work is to understand the amount of service provided by the current single-agency radio systems. A "signal capacity model" was developed, which uses Federal Government Master File (GMF) license data to calculate the number of independent radio signals that could be received by a mobile user at 1-mile increments within a 100-mile radius of Washington, D.C. Since various radio network architectures transmit the same signal from multiple sites, different algorithms were used to calculate the signal capacity for different types of mobile networks. Peak and average signal capacity maps were produced, based on different assumptions about the probable location of users. This data will form the basis for the design of possible alternatives for future shared radio systems.

S. Voran, "Compensating for gain in objective quality estimation algorithms," in *Proc. of the International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, Montreal, May 2004.

When objectively estimating speech, audio, or video quality, it is often necessary to compensate for a system gain or to "gain match" two or more signals. One can take three views of a system, leading to three different definitions of gain, and three different gain compensation solutions: one that minimizes distortion, one that matches input-output power, and one that maximizes signal-todistortion ratio. We derive these three solutions, describe the algebraic and geometric relationships between them, and provide a generalized result that subsumes all three. We provide examples showing that these three

solutions do differ in practical quality estimation situations. We also report some of the gain compensation choices found in the quality estimation literature.

S.D. Voran, "A bottom-up algorithm for estimating time-varying delays in coded speech," in *Proc. of the 3rd International Conference on Measurement of Speech and Audio Quality in Networks (MESAQIN),* Prague, Czech Republic, May 2004.

In packetized speech transmission, end-to-end delay can vary, even over short timescales. Estimating the resulting speech delay histories is critical to diagnostic and quality estimation efforts. We present a new bottom-up algorithm for estimating time-varying speech delays. The bottom-up approach is well-suited to real-time implementation. The algorithm works with very low-rate codecs as well as the higher-rate codecs that are more common in VoIP applications. We describe the new algorithm in some detail and provide descriptions of the databases and techniques used to develop and test the new algorithm.

Journal Articles

M.H. Brill, J. Lubin, P. Costa, S. Wolf, and J. Pearson, "Accuracy and cross-calibration of video quality metrics: New methods from ATIS/T1A1," *Signal Processing: Image Communication 19*, No. 2, pp. 101-107, Feb. 2004.

Video quality metrics (VQMs) have often been evaluated and compared using simple measures of correlation to subjective mean opinion scores from panels of observers. However, this approach does not fully take into account the variability implicit in the observers. We present techniques for determining the statistical resolving power of a VQM, defined as the minimum change in the value of the metric for which subjective test scores show a significant change. Resolving power is taken as a measure of accuracy. These techniques have been applied to the video quality experts group (VQEG) data set and incorporated into the recent Alliance for Telecommunications Industry Solutions (ATIS) Committee T1A1 series of technical reports (TRs), which provide a comprehensive framework for characterizing and validating full-reference VQM. These approved TRs, while not standards, will enable the US telecommunications industry to incorporate VQMs into contracts and tariffs for compressed video distribution. New methods for assessing VQM accuracy and cross-calibrating VQMs are an integral part of the framework. These methods have been applied to two VQMs at this point: peak-signal-to-noise ratio and the version of Sarnoff's just noticeable difference metric (JNDmetrix®) tested by VQEG (Rapporteur Q11/12 (VQEG): Final report from the VQEG on the validation of objective models of video quality assessment, June 2000). The framework is readily extensible to additional VQMs.

P. McKenna and G. Hand, "Radio propagation models," *MissionCritical Communications 19,* No. 5, Jun. 2004.

It is difficult to provide reliable radio service in today's crowded spectrum. The use of more precise system design and spectrum management tools can help.

M.H. Pinson and S. Wolf, "A new standardized method for objectively measuring video quality," *IEEE Trans. on Broadcasting 50*, No. 3, pp. 312-322, Sep. 2004.

The National Telecommunications and Information Administration (NTIA) General Model for estimating video quality and its associated calibration techniques were independently evaluated by the Video Quality Experts Group (VQEG) in their Phase II Full Reference Television (FR-TV) test. The NTIA General Model was the only video quality estimator that was in the top performing group for both the 525-line and 625-line video tests. As a result, the American National Standards Institute (ANSI) adopted the NTIA General Model and its associated calibration techniques as a North American Standard in 2003. The International Telecommunication Union (ITU) has also included the NTIA General Model as a normative method in two Draft Recommendations. This paper presents a description of the NTIA General Model and its associated calibration techniques. The independent test results from the VQEG FR-TV Phase II tests are summarized, as well as results from eleven other subjective data sets that were used to develop the method.

Unpublished Presentations

N. DeMinco, "Prediction of near-field intensity for a radar phased array antenna," National Radio Science Meeting, URSI, Univ. of Colorado, Boulder, Jan. 2004.

C. Ford and G. Hand, "Propagation of VHF signals across rough oceans close to shore: A comparision of models," National Radio Science Meeting, URSI, Univ. of Colorado, Boulder, Jan. 2004.

R. Matheson, "Alternative spectrum management techniques," tutorial, International Symposium on Advanced Radio Technologies, March 2004.

R. Matheson, "Somewhere, over the spectrum: Overseeing the Nation's radio airwaves," Boulder Labs 50th Anniversary Lecture Series, Aug. 4, 2004.

R. Matheson, "Spectrum measurements," invited presentation, National Academy of Sciences, Committee on Wireless Technology Prospects and Policy Options, San Diego, Jul. 22, 2004.

F. Sanders, "Radar pulse measurements and implications for spectrum emission compliance," Tri-Service Radar Symposium, Albuquerque, NM, Jun. 21, 2004.

F. Sanders, "Radar spectrum measurement techniques and implications for the RSEC and spectrum efficiency," invited talk, Naval Research Laboratory workshops on radar spectrum allocation issues, radar emission and measurement standards, Washington, Oct. 21, 2003.

R. Stafford "Voice over Internet Protocol and the convergence of communications technologies," invited talk, Univ. of Colorado, Boulder, Jan. 29, 2004.

Conferences Sponsored by ITS

International Symposium on Advanced Radio Technologies (ISART 2004)

The International Symposium on Advanced Radio Technologies (ISART 2004) was held March 2-4, 2004. This symposium explores the current state of the radio art with an eye towards forecasting the use of wireless technology in the future. In order to accomplish this goal, ISART brings together a diverse collection of people from academia, business, and government agencies to discuss the interplay between technological "how-to," the possibilities and restrictions created by regulation and policy, and the economic motivation of the business world. For more information see: http://www.its.bldrdoc.gov/meetings/art/.

Standards Leadership Roles

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

Randall S. Bloomfield, Vice-Chair of the ISSI Task Group and Vice-Chair of the P25 Systems Architecture Working Group (both within the APCO Project 25 Interface Committee).

Paul M. McKenna, National Chair of U.S. contingent of ITU-R Study Group 3 (Radiowave Propagation); Chair of Drafting Groups 3J6 and 3M-3B.

William J. Pomper, Chair of APCO/NASTD/FED Project 25 Encryption Task Group; Member of TIA/TR-8 — Mobile and Personal Private Radio Standards Committee.

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

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

Neal B. Seitz, Vice Chair of ITU-T Study Group 13 (Next Generation Networks); Chair of ITU-T Study Group 13 Working Party 4 (OAM and QoS); Vice Chair of ATIS Network Performance, Reliability, and Quality of Service Committee (PRQC — formerly ANSI-accredited Technical Subcommittee T1A1).

Arthur Webster, Co-chair of Video Quality Experts Group (VQEG); Rapporteur for Question 21/9 (Objective and subjective methods for evaluating conversational audiovisual quality in multimedia services) in ITU-T Study Group 9 (Integrated broadband cable networks and television and sound transmission); Chair of Joint Rapporteur Group on Multimedia Quality Assessment (JRG-MMQA).

Representative Technical Contributions

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

Emergency Telecommunications Service Projects (authors/editors include A. Webster)

- "User plane security guidelines and requirements for ETS," ANSI Standard, ATIS PRQC.
- "User plane priority levels in IP networks and services," ATIS TR, ATIS PRQC.
- "Requirements for preferential telecommunications over IPCablecom networks," J.260, ITU-T SG 9, went out for TAP, May 2004.
- "Specifications for preferential telecommunications over IPCablecom networks," DNR J.pref, ITU-T SG 9.
- Draft TR on user plane security requirements in next generation networks, ATIS PRQC.

High-power Radars and Spectrum Sharing (authors include F.H. Sanders)

- "Reduction of unwanted emissions of radar systems operating above 400 MHz," PDNR M.1314, ITU-R WP-8B.
- "Technical and operational characteristics and protection criteria of radiodetermination and meteorological radars in the 2 900-3 100 MHz band," PDNR M.1460, ITU-R WP-8B.
- "Test results illustrating the susceptibility of maritime radionavigation radars to emissions from digital communication and pulsed systems in the bands 2 900-3 100 and 9 200-9 500 MHz," DNR, ITU-R WP-8B

Quality of Service (authors include N.B. Seitz)

- "Mapping between ITU-T (Y.1541/Y.1221) and 3GPP (TS 23-107) QoS classes and traffic descriptors," ITU-T SG 13, WP 4, Feb. 2004.
- "Survey of IP network QoS architecture and protocol standardization activities," T1A1/2003-116 (T1S1/2003-440), May 2004.

APCO Project 25 (authors include R.S. Bloomfield)

- P25 end-to-end performance topics, ISSI TG and UNS (P25 P25/TR-8), Oct. 2003.
- ISSI (voice) measurement and performance topics, ISSI TG and UNS (P25 P25/TR-8), Jan. 2004.
- Discussion paper: "Approach for P25/TR-8 (IPPTG) documentation of ISSI interoperability test procedures," IPPTG (P25/TR-8), Jan. 2004.
- Discussion paper: "Approach for developing ISSI interoperability test procedures for voice operation in trunked systems," IPPTG (P25/TR-8), Jan. 2004.
- Issue I of planned new TIA/ANSI standard: Project 25 ISSI measurement methods for voice services, ISSI TG (P25/TR-8), Mar. 2004.
- Issue H of planned new TIA/ANSI standard: Project 25 ISSI performance specifications for voice services, ISSI TG (P25/TR-8), Mar. 2004.
- Discussion paper: "Proposal for IPPTG development of interoperability test procedures for P25 wide area services," IPPTG (P25/TR-8), Mar. 2004.
- ITS comments on "APCO P25 ISSI messages definition" Draft TIA-102.BACA, version 0, Oct. 16, 2003 (ISSIMsgDef_Draftv0_'031016), TR-8.19 (P25/TR-8), Mar. 2004.
- P25 end-to-end and ISSI performance issues, P25 UNS special meeting (P25/TR-8), May 2004.
- Discussion paper: "Selected issues as of June 8, 2004 on ISSI measurement methods for voice services draft standard," ISSI TG (P25/TR-8), Jun. 2004.
- Discussion paper: "Selected issues as of June 8, 2004 on ISSI performance recommendations for voice services draft standard," ISSI TG (P25/TR-8), Jun. 2004.
- ISSI measurement and performance update, ISSI TG (P25/TR-8), Jun. 2004.

Ultrawideband (authors include R. Achatz, M. Cotton, and R. Dalke)

- "Estimating and graphing the amplitude probability distribution function of complex-baseband signals,"IEEE 802.15.3a.

Video Quality (authors include S. Wolf, M. Pinson)

- "Objective perceptual video quality measurement techniques for digital cable television in the presence of a full reference," ITU-T Recommendation J.144R, approved Mar. 2004.
- "Methodological framework for specifying accuracy and cross-calibration of video quality Metrics (VQM)," ITU-T Recommendation J.149, approved Mar. 2004.

Abbreviations/Acronyms

2D	two **d**imensional
3D	three **d**imensional
3G	third **g**eneration

A

AAR	**A**ssociation of **A**merican **R**ailroads
AFSK	**A**udio **F**requency **S**hift **K**eying
AGILE	**A**dvanced **G**eneration of **I**nteroperability for **L**aw **E**nforcement
ANS	**A**merican **N**ational **S**tandard
ANSI	**A**merican **N**ational **S**tandards **I**nstitute
APCO	**A**ssociation of **P**ublic-Safety **C**ommunications **O**fficials
APD	**A**mplitude **P**robability **D**istribution
APM	**A**dvanced **P**ropagation **M**odel
AQMS	**A**udio **Q**uality **M**easurement **S**ystem
ASC	**A**verage **S**ignal **C**apacity
ASCII	**A**merican **S**tandard **C**ode for **I**nformation **I**nterchange
ATB	**a**ntenna **t**est**b**ed
ATIS	**A**lliance for **T**elecommunications **I**ndustry **S**olutions
ATM	**A**synchronous **T**ransfer **M**ode
AUGNET	**A**d hoc **U**AV and **G**round **Net**working

B

BAWT	**B**roadband **A**rbitrary **W**aveform **T**ransmitter
BPL	**B**roadband over **P**ower **L**ine
BWCF	**B**andwidth **C**orrection **F**actor

C

CD	**c**ompact **d**isk
CDA	**C**ode **D**omain **A**nalyzer
CEA	**C**onsumer **E**lectronics **A**ssociation
CIF	**C**ommon **I**ntermediate **F**ormat
CIP	**C**ritical **I**nfrastructure **P**rotection
CommTech	**Comm**unications **Tech**nology
CONUS	**Con**tinental **U.S.**
COPS	Office of **C**ommunity **O**riented **P**olicing **S**ervice
CRADA	**C**ooperative **R**esearch **a**nd **D**evelopment **A**greement
CRPL	**C**entral **R**adio **P**ropagation **L**aboratory
CRT	**c**athode **r**ay **t**ube
CSPM	**C**ommunication **S**ystem **P**erformance **M**odel
CSPT	**C**ommunication **S**ystem **P**lanning **T**ool
CW	**c**ontinuous **w**ave

D

DAQ	**D**elivered **A**udio **Q**uality
dB	**d**eci**b**el
DC	**d**irect **c**urrent
DFS	**D**ynamic **F**requency **S**election
DGPS	**D**ifferential **GPS**
DHS	**D**epartment of **H**omeland **S**ecurity
DLL	**D**ynamic **L**ink **L**ibrary
DOC	**D**epartment **o**f **C**ommerce
DOD	**D**epartment **o**f **D**efense
DOJ	**D**epartment **o**f **J**ustice
DNR	**D**raft **N**ew **R**ecommendation
DSCP	**D**igital **S**ampling **C**hannel **P**robe
DS-UWB	**D**irect-**S**equence **U**ltra**w**ide**b**and
DT&E	**D**evelopmental **T**esting and **E**valuation
DTV	**d**igital **t**elevision

E

EAS	**E**mergency **A**lert **S**ystem
EIA	**E**lectrical **I**ndustries **A**ssociation
EMC	**e**lectro**m**agnetic **c**ompatibility
EMOS	**E**stimated **M**ean **O**pinion **S**core
EMS	**E**mergency **M**edical **S**ervices
ESSA	**E**nvironmental **S**cience **S**ervices **A**dministration
ETS	**E**mergency **T**elecommunications **S**ervice
EVA	**Ev**aluation License **A**greement

F

FAA	**F**ederal **A**viation **A**dministration
FCC	**F**ederal **C**ommunications **C**ommission
FED	**Fed**eral
FLEWUG	**F**ederal **L**aw **E**nforcement **W**ireless **U**sers' **G**roup
FM	**f**requency **m**odulation
FPIC	**F**ederal **P**artnership for **I**nteroperability **C**ommunications
FQT	**F**ormal **Q**ualification **T**est
FR-TV	**F**ull **R**eference **Tele**vision
FSK	**F**requency **S**hift **K**eying
FTTA	**F**ederal **T**echnology **T**ransfer **A**ct
FY	**F**iscal **Y**ear

G

G3GRA	**R**adio **A**spects of **G**SM/**3G** and Beyond
GB	**g**iga**b**yte
GCC	**G**roup **C**ommunications **C**enter
GETS	**G**overnment **E**mergency **T**elecommunications **S**ervice
GHz	**g**iga**h**ert**z**
GIF	**G**raphics **I**nterchange **F**ormat
GIS	**G**eographic **I**nformation **S**ystem
GJXDM	**G**lobal **J**ustice **X**ML **D**ata **M**odel
GLOBE	**G**lobal **L**and **O**ne-km **B**ase **E**levation
GMF	**G**overnment **M**aster **F**ile
GPRS	**G**eneral **P**acket **R**adio **S**ervice
GPS	**G**lobal **P**ositioning **S**ystem
GSM	**G**lobal **S**ystem for **M**obile
GUI	**G**raphical **U**ser **I**nterface
GWSSUS	**G**aussian **W**ide **S**ense **S**tationary **U**ncorrelated **S**cattering

H

HATS	**H**ead **a**nd **T**orso **S**imulators
HD	**h**igh **d**efinition
HDTV	**H**igh **D**efinition **Tele**vision
HF	**h**igh **f**requency
HTML	**H**yper**t**ext **M**arkup **L**anguage
HTTP	**H**yper**t**ext **T**ransfer **P**rotocol

I

IEEE	**I**nstitute of **E**lectrical and **E**lectronics **E**ngineers
IETF	**I**nternet **E**ngineering **T**ask **F**orce
IF	**i**ntermediate **f**requency
INFOSEC	**Info**rmation System **Sec**urity
IP	**I**nternet **P**rotocol
IPG	**I**ntersessional **P**lanning **G**roup
IPPTG	**I**nteroperability **P**rocess and **P**rocedures **T**ask **G**roup
IRAC	**I**nterdepartment **R**adio **A**dvisory **C**ommittee
IRL	**I**nteroperability **R**esearch **L**aboratory
ISART	**I**nternational **S**ymposium on **A**dvanced **R**adio **T**echnologies
ISM	**I**ndustrial, **S**cientific, and **M**edical
ISSI	**I**nter-rf **Sub**system **I**nterface
IT	**I**nformation **T**echnology
ITM	**I**rregular **T**errain **M**odel
ITS	**I**nstitute for **T**elecommunication **S**ciences
ITSA	**I**nstitute for **T**elecommunication **S**ciences and **A**eronomy
ITU	**I**nternational **T**elecommunication **U**nion
ITU-R	**I**nternational **T**elecommunication **U**nion — **R**adiocommunication Sector
ITU-T	**I**nternational **T**elecommunication **U**nion — **T**elecommunication Standardization Sector

J

JRG	**J**oint **R**apporteur **G**roup
JWN	**J**ustice **W**ireless **N**etwork

K

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

L

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

M

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

N

NASTD	**N**ational **A**ssociation of **S**tate **T**elecommunications **D**irectors
NCS	**N**ational **C**ommunications **S**ystem
NDRS	**N**ational **D**istress and **R**esponse **S**ystem
NGN	**N**ext **G**eneration **N**etwork
NI	**N**ational **I**nstruments
NIJ	**N**ational **I**nstitute of **J**ustice
NIST	**N**ational **I**nstitute of **S**tandards and **T**echnology
NOAA	**N**ational **O**ceanic and **A**tmospheric **A**dministration
NORAD	**Nor**th American **A**erospace **D**efense Command
NRL	**N**aval **R**esearch **L**aboratory
NRSSC	**N**etwork **R**eliability and **S**ecurity **Sub**committee
NS/EP	**N**ational **S**ecurity and **E**mergency **P**reparedness
NTIA	**N**ational **T**elecommunications and **I**nformation **A**dministration
NWR	**N**OAA **W**eather **R**adio
NWS	**N**ational **W**eather **S**ervice

O

OAM	**O**peration, **A**dministration and **M**aintenance
OFDM	**O**rthogonal **F**requency-**D**ivision **M**ultiplexing
OLES	**O**ffice of **L**aw **E**nforcement **S**tandards
OMB	**O**ffice of **M**anagement and **B**udget
OQPSK	**O**ffset **Q**uadrature **P**hase-**S**hift **K**eying
OSM	**O**ffice of **S**pectrum **M**anagement
OT	**O**ffice of **T**elecommunications
OTN	**O**ptical **T**ransport **N**etwork
OTP	**O**ffice of **T**elecommunications **P**olicy

P

P25	**P**roject **25**
PBS	**P**ublic **B**roadcasting **S**ystem
PC	**p**ersonal **c**omputer
PCS	**P**ersonal **C**ommunications **S**ervices
PDD	**P**residential **D**ecision **D**irective
PDNR	**P**reliminary **D**raft **N**ew **R**ecommendation
PESQ	**P**erceptual **E**valuation of **S**peech **Q**uality
PLMN	**P**ublic **L**and **M**obile **N**etwork
PRF	**P**ulse **R**epetition **F**requency
PRQC	Network **P**erformance, **R**eliability and **Q**uality of Service **C**ommittee
PSTN	**P**ublic **S**witched **T**elephone **N**etwork
PSWAC	**P**ublic **S**afety **W**ireless **A**dvisory **C**ommittee
PSWN	**P**ublic **S**afety **W**ireless **N**etwork

Q

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

R

R&D	**r**esearch and **d**evelopment
RCG	**R**adar **C**orrespondence **G**roup
RF	**r**adio **f**requency
RFID	**R**adio **F**requency **Id**entification
RFSS	**R**adio **F**requency **S**ub**s**ystem
RLAN	**R**adio **L**ocal **A**rea **N**etwork
RNSS	**R**adio**n**avigation **S**atellite **S**ervice
RRC	**R**egional **R**adio **C**onference
RSEC	**R**adar **S**pectrum **E**ngineering **C**riteria
RSMS	**R**adio **S**pectrum **M**easurement **S**ystem
RSMS-4	**4**th Generation **RSMS**

S

SAFECOM	Public **Safe**ty Wireless **Com**munications
SAME	**S**pecific **A**rea **M**essage **E**ncoding
SC	**S**ignal **C**apacity
SD	**S**tandard **D**efinition
SDMA	**S**pace **D**ivision **M**ultiple **A**ccess
SDTV	**S**tandard **D**efinition **Tele**vision
SG	**S**tudy **G**roup
SIP	**S**ession **I**nitiation **P**rotocol
SIPRNET	**S**ecret **I**nternet **P**rotocol **R**outable **Net**work
SIT	**S**ystem **I**ntegration **T**est
SNMP	**S**imple **N**etwork **M**anagement **P**rotocol
SONET	**S**ynchronous **O**ptical **Net**work
SOR	**S**tatement **o**f **R**equirements
STG	**S**ystems **T**ask **G**roup
SUT	**S**ystem **U**nder **T**est

T

T&E	**t**est and **e**valuation
TA Services	**T**elecommunications **A**nalysis **Services**
TAP	**T**raditional **A**pproval **P**rocess
TG	**T**ask **G**roup
TIA	**T**elecommunications **I**ndustry **A**ssociation
TIREM	**T**errain **I**ntegrated **R**ough **E**arth **M**odel
TR	**T**echnical **R**eport
TSB	**T**elecommunications **S**ystems **B**ulletin

U

UAV	**u**nmanned **a**erial **v**ehicle
UHF	**u**ltra **h**igh **f**requency
UNIX	**uni**ple**x**ed information and computing service
UNS	**U**ser **N**eeds **S**ubcommittee
URL	**U**niform **R**esource **L**ocator
URSI	**I**nternational **U**nion of **R**adio **S**cience
US	**U**nited **S**tates
USCG	**U.S. C**oast **G**uard
USGS	**U.S. G**eological **S**urvey
UWB	**u**ltra**w**ide**b**and

V

VHF	**v**ery **h**igh **f**requency
VoIP	**V**oice **o**ver **I**nternet **P**rotocol
VPN	**V**irtual **P**rivate **N**etwork
VQEG	**V**ideo **Q**uality **E**xperts **G**roup
VQM	**V**ideo **Q**uality **M**easurement
VSA	**v**ector **s**ignal **a**nalyzer

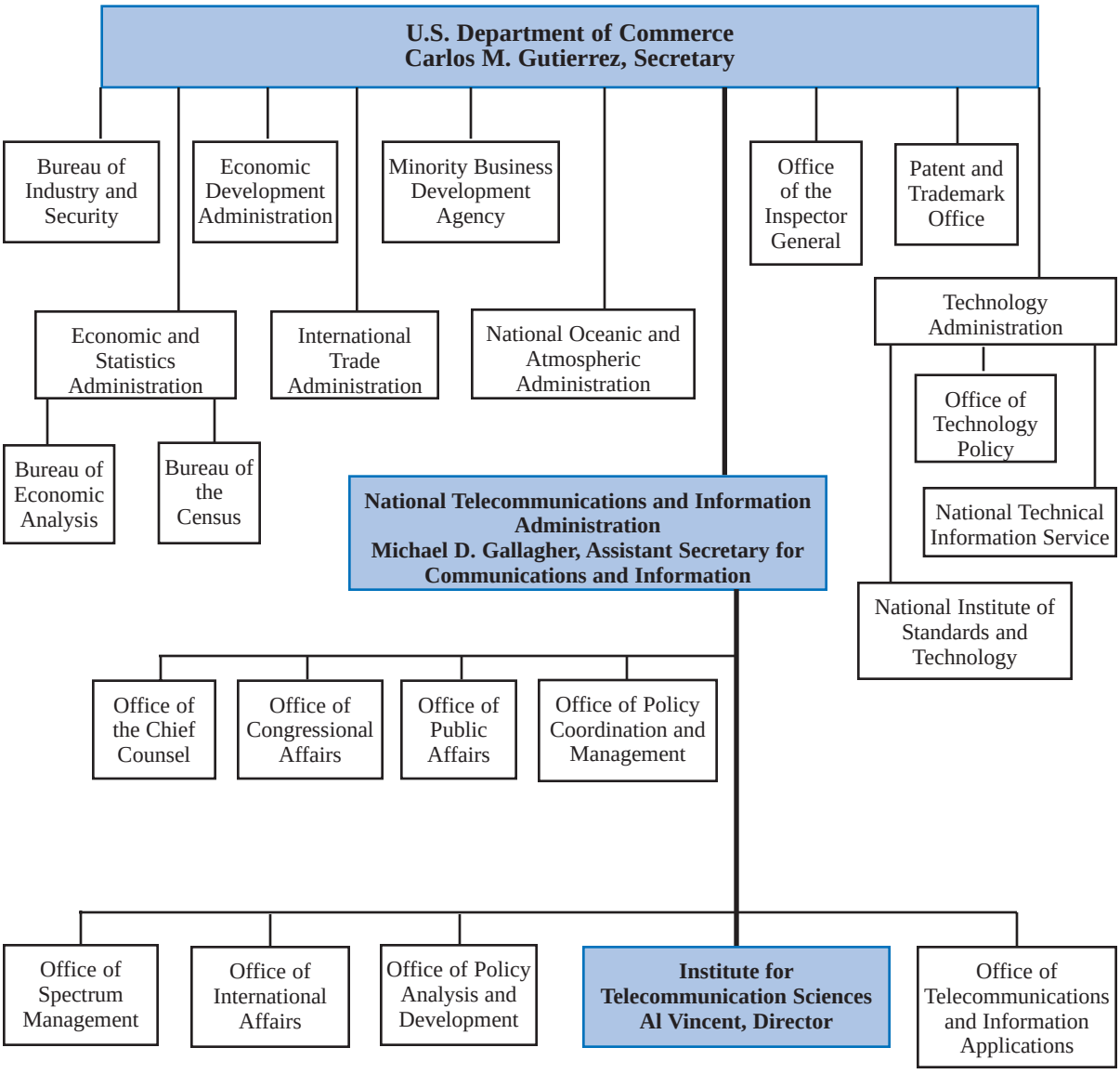
W

WCTF	**W**ireless **C**ommunications **T**ask **F**orce
Wi-Fi	**Wi**reless **Fi**delity
WLAN	**W**ireless **LAN**
WMO	**W**ireless **M**anagement **O**ffice
WNRC	**W**ireless **N**etworks **R**esearch **C**enter
WP	**W**orking **P**arty
WPAN	**W**ireless **P**ersonal **A**rea **N**etwork
WTSA	**W**orld **T**elecommunication **S**tandardization **A**ssembly

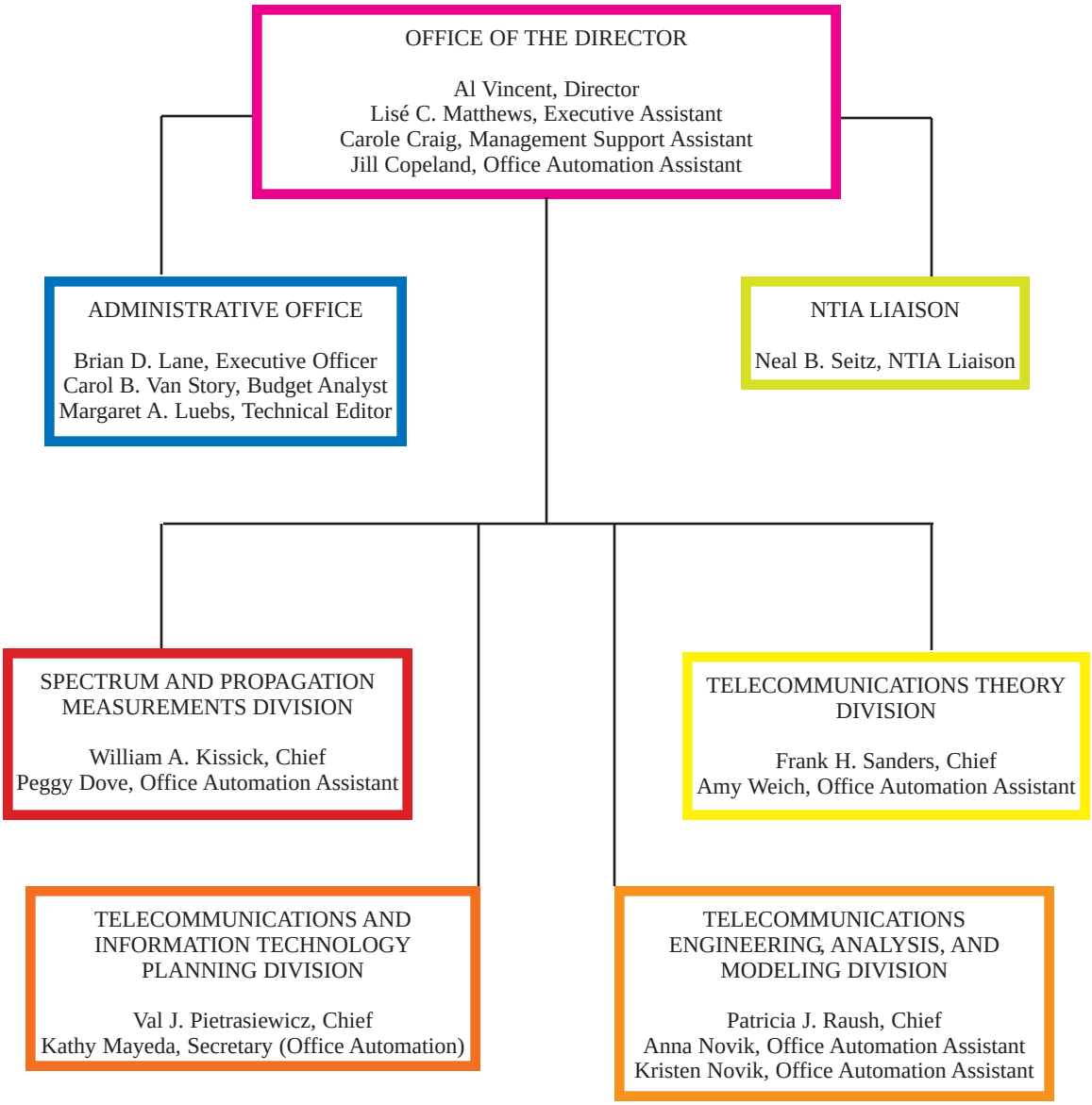
X

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

DOC/NTIA Organization Chart



ITS Organization Chart



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